PHYSICAL REVIEW C VOLUME 17, NUMBER 1 JANUARY 1978

Energy dependence of $^{16}O(^6Li,d)^{20}Ne$ from 19.8–32 MeV

L. J. House and K. W. Kemper
Department of Physics, Florida State University, Tallahassee, Florida 32306
(Received 24 February 1977)

$^{16}O(^6Li,d)$ excitation functions have been measured in the laboratory energy range from 19.8 to 32 MeV, in 200 keV steps, for the ^{20}Ne 0^+ (0.0 MeV) and 2^+ (1.62 MeV) states at 7.5° and for the 2^+ (1.62 MeV) and 4^+ (4.25 MeV) states at 17.5°. The fluctuations in the data are less than ±25% over this energy region. At 20, 24, and 28 MeV the cross sections at 165° are at least 5–10 times smaller than at 25°. Comparisons between the data and distorted-wave Born approximation calculations over this energy range show the reaction mechanism to be more complicated than a simple one-step α particle transfer.

[NUCLEAR REACTIONS $^{16}O(^6Li,d)^{20}Ne(0^+,0.0$ MeV; 2^+, 1.62 MeV; 4^+, 4.25 MeV), $E(^6Li)=19.8$–32 MeV, $\Delta E=200$ keV; measured $\sigma(E)$ at $\theta_{lab}=7.5°$ and 17.5°.]

The reaction $(^6Li,d)$ has been used extensively to extract α-particle spectroscopic strengths in the $1s$-$0d$ and $0f$-$1p$ shells[1,2]. One anomalous reaction in this group is $^{16}O(^6Li,d)^{20}Ne$. At $E(^6Li)=$ 20 MeV,[2] the ratios of spectroscopic factors extracted from distorted-wave Born-approximation (DWBA) calculations for the first 0^+, 2^+, and 4^+ states in ^{20}Ne were found to be 1 : 1 : 1 while at 32 MeV,[3,4] the ratios were found to be 1 : 0.3 : 0.2. Since the DWBA calculations for the 4^+ state at both 29 and 32 MeV do a poor job of reproducing the angular distributions,[2-4] the extracted spectroscopic factor for this state is highly unreliable. However, the fits for the 0^+ and 2^+ state data are quite reasonable, especially in the region of the first stripping maximum, so that the energy dependence of the relative spectroscopic factor for the 2^+ state is due to more than bad "fits" to the data. This problem must be solved before reliable α-particle structure information can be obtained from $(^6Li,d)$ reactions in this mass region.

Previous attempts to resolve this spectroscopic factor discrepancy have involved repeating the original 20 MeV Pennsylvania[2] experiment at Rochester, where the 32 MeV measurements were performed.[3,4] The results of the two 20 MeV measurements are in excellent agreement. In the present note, measurements of the energy dependence of the $^{16}O(^6Li,d)^{20}Ne$ reaction are reported. These measurements were made to determine whether resonant-cluster transfer contributions of the type proposed by Carlson and Johnson[5] could be responsible for the apparent energy dependence of the spectroscopic factors.

The ^6Li ions were produced in an inverted sputter source[6] and accelerated by the Florida State University super FN tandem Van de Graaff accelerator. The targets were self-supported 50-100 $\mu g/cm^2$ Al_2O_3 made by electron bombardment of sapphire crystals. The targets were about 60 keV thick to 20 MeV ^6Li. The experimental data were taken in a standard scattering chamber with counter telescopes at the lab angles 7.5° and 17.5°. Aluminum absorbers were used in front of the detectors to stop the elastic ^6Li particles from reaching the detectors. Elastic scattering from the Al and O in the target was measured with a fixed detector so that changes in target conditions could be monitored.

The counter telescope at 7.5° consisted of a 320 μm Si surface barrier ΔE detector with a 4 mm Si(Li) detector and the one at 17.5° contained two Si surface barrier detectors: a 700 μm ΔE and a 2 mm E. The signals were processed with standard electronics and sorted into linear energy spectra in an on-line computer. The absolute cross section was determined as described in Ref. 7 and its error is 11%. The most serious experimental problem in the present work was carbon buildup on the target which can interfere with the measurement of the yield of the 4^+ state in ^{20}Ne. This potential problem is illustrated by the $^{12}C,^{16}O(^6Li,d)$ spectra shown in Fig. 1. The carbon buildup was monitored by checking for yield from $^{12}C(^6Li,d)^{16}O$ (6.92 MeV). The targets were changed when the population of this state could be observed. The experimental energy resolution was 150 keV and the relative errors in the data points were 8%. Figure 2 shows spectra at 7.5° taken at 20 and 28 MeV. At 20 MeV, the 4^+ (4.25 MeV) yield is large and easily extractable. However, above about 22 MeV the 4^+ intensity was insufficient to extract reliably. At 17.5° the detectors were not thick enough to stop the ground state deuterons above about 22 MeV bombarding energy.

The excitation functions for the 0^+ and 2^+ states at 7.5° and 2^+ and 4^+ states at 17.5° taken in 200 keV steps, are shown in Figs. 3 and 4. To investigate the energy dependence that might be expec-

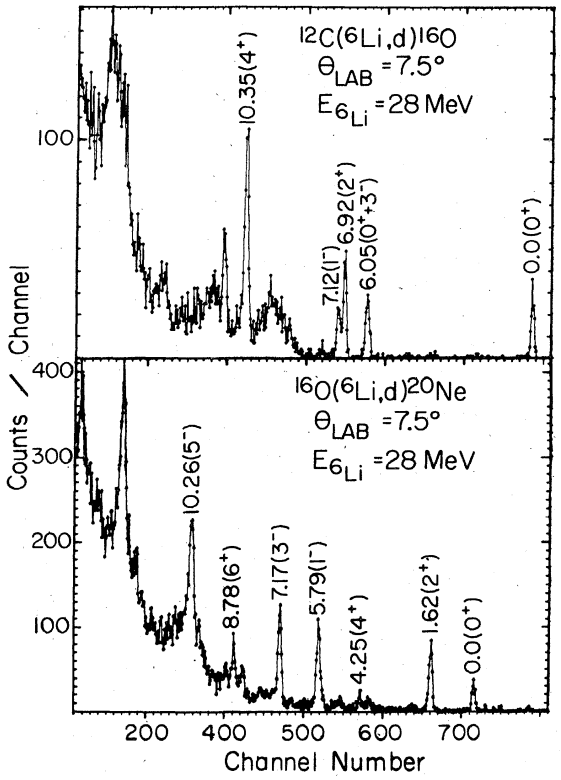

FIG. 1. Comparison spectra showing the possible interference of reaction products from $^{12}C(^6Li,d)$ with those from $^{16}O(^6Li,d)$.

ted for this reaction if it is a direct one-step α transfer process, zero-range DWBA calculations were carried out with the code DWUCK. The ^6Li optical model parameters used in the calculations were those of Schumacher *et al.*[8] and the deuteron parameters were those shown previously to fit $^{19}F(^3He,d)^{20}Ne$ data.[9] The transfer was treated as an α cluster transfer with the four particles transferred into $1s$-$0d$ shell orbits so that the number of nodes and orbital angular momentum of the bound particle are given by $2N+L=8$. The bound state geometry used was $R=1.25(16)^{1/3}$ and $a=65$ and the depth of the well was varied until the proper binding energy for each state was obtained. The results of the calculations are shown in Figs. 3 and 4. The spectroscopic factors relative to the ground state for the calculations as normalized in Figs. 3 and 4 are 1 : 0.65 : 0.61.

To check for the presence of statistical compound nucleus contributions, data were taken at 15° and 25° and with the same detectors rotated back to 155° and 165° at 20, 24, and 28 MeV. The cross sections at the back angles were at least 3 times smaller for the 4^+ state, and 5–10 times smaller for the 0^+ and 2^+ states than at the forward angles, indicating that the angular distributions are not symmetric about 90°. At 32 MeV, Gunn *et al.*[4] have shown that the angular distributions for these states are also not symmetric about 90°. These back angle data indicate that statistical compound nuclear contributions are small in this reaction.

Comparison of the measured yield curves with the DWBA calculations in Figs. 3 and 4 shows the presence of structure for the 0^+ and 2^+ states below 26 MeV which do not appear to be explainable assuming a direct α transfer. The present data indicate a complex reaction mechanism for $^{16}O(^6Li,d)$ in the energy range studied to date. In addition to possible resonant exchange contributions around 24 MeV bombarding energy, two-step contributions could be important in this energy range. Previous measurements of the $^{19}F(^3He,d)^{20}Ne$ reaction[9] showed that inelastic excitation by the outgoing deuterons was an important component in the population of both the ^{20}Ne 2^+ and 4^+ states. Since the outgoing deuterons in the $(^3He,d)$

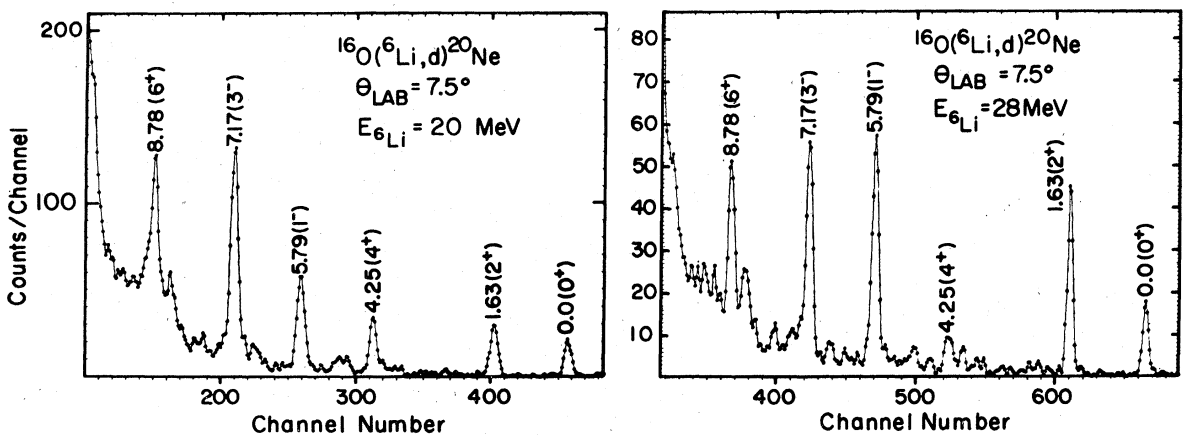

FIG. 2. Sample spectra at 20 and 28 MeV from $^{16}O(^6Li,d)$.

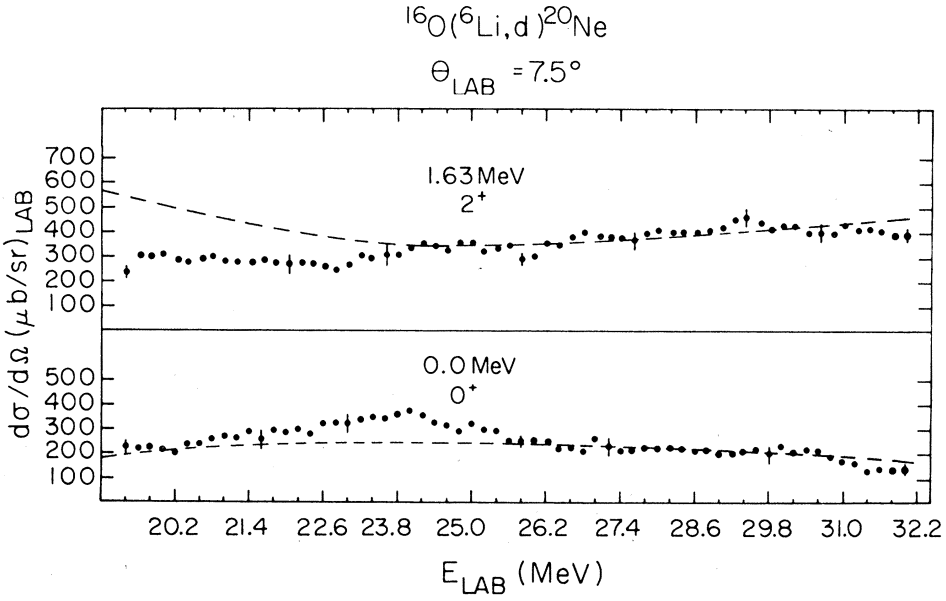

FIG. 3. Excitation functions for $^{16}O(^{6}Li,d)$ at 7.5°. Representative error bars are shown. The dashed curves are DWBA calculations done to show the energy dependence that could be expected from a direct α transfer.

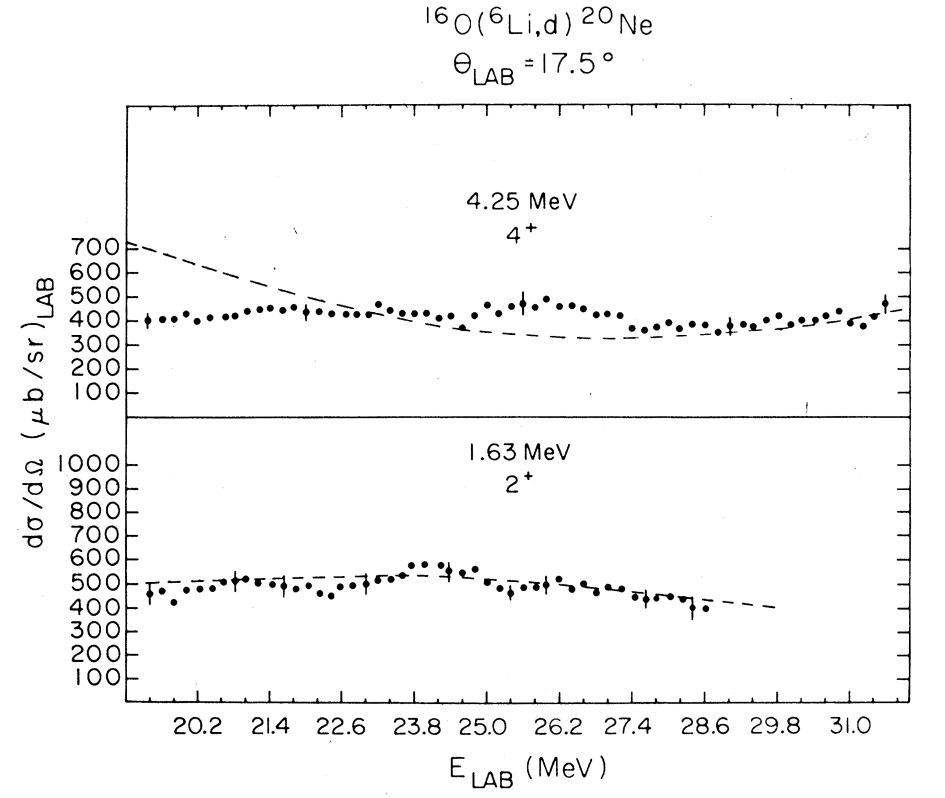

FIG. 4. Excitation functions for $^{16}O(^{6}Li,d)$ at 17.5°. Representative error bars are shown. The dashed curves are DWBA calculations.

case have roughly the same energy as for the present (^{6}Li,d) studies, two-step processes can be important in the ^{16}O(^{6}Li,d)^{20}Ne reaction as well, and need to be investigated further. The present study shows that measurements at much higher energies are extremely important for resolving the ^{16}O(^{6}Li,d) spectroscopic problem.

The authors acknowledge the aid of J. D. Fox in this work and the support of the National Science Foundation.

---

[1]N. Anantaraman, C. L. Bennett, J. P. Draayer, H. W. Fulbright, H. E. Gove, and J. Toke, Phys. Rev. Lett. 35, 1131 (1975); K. Bethge, Annu. Rev. Nucl. Sci. 20, 255 (1970).

[2]H. T. Fortune, Argonne National Laboratory, Physics Division, Informal Report No. PHY-1973B, 1973 (unpublished), pp. 287–323.

[3]N. Anantaraman, J. P. Draayer, and H. E. Gove, Bull. Am. Phys. Soc. 20, 598 (1975).

[4]G. D. Gunn, R. N. Boyd, N. Anantaraman, D. Shapira, J. Toke, and H. E. Gove, Nucl. Phys. A275, 524 (1977).

[5]R. R. Carlson and D. J. Johnson, Phys. Rev. Lett. 25, 172 (1970).

[6]K. R. Chapman, Nucl. Instrum. Methods 124, 299 (1975).

[7]G. E. Moore and K. W. Kemper, Phys. Rev. C 14, 977 (1976).

[8]P. Schumacher, N. Ueta, H. H. Duhm, K. I. Kubo, and W. J. Klages, Nucl. Phys. A212, 573 (1973).

[9]A. W. Obst and K. W. Kemper, Phys. Rev. C 8, 1682 (1973).