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$(d, {}^2\mathrm{He})$ reaction at $E_d = 99$ MeV

K. B. Beard, J. Kasagi, E. Kashy, and B. H. Wildenthal
Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824

D. L. Freisel and H. Nann
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

R. E. Warner
Oberlin College, Oberlin, Ohio 44074
and Michigan State University, East Lansing, Michigan 48824

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Differential cross sections at $15° \leq \theta_L \leq 30°$ of the ${}^{12}\mathrm{C}(d, {}^2\mathrm{He}){}^{12}\mathrm{B}$ reaction were measured at a bombarding energy of $E_d = 99.2$ MeV.

[NUCLEAR REACTIONS ${}^{12}\mathrm{C}(d, {}^2\mathrm{He})$, $E_d = 99.2$ MeV; measured $\sigma(E_f, \theta)$.]

The ability to measure the strengths of $\Delta L = 0$, $\Delta J = \Delta S = \Delta T = |\Delta T_z| = 1$ transitions in the T_z direction of increasing neutron excess would be of great general utility in probing nuclear structure and would have special interest in answering problems such as that of determining the spectrum for electron capture on ${}^{56}\mathrm{Fe}$ in the astrophysical environment leading to the formation of neutron stars.[1] The reaction $(d, {}^2\mathrm{He})$, in which the reaction product is the "diproton" singlet state $T = 1$, $S = 0$, is, in principle, ideally suitable as a probe for such transitions. It provides a charge-exchange mode induced by a charged, nonradioactive beam; moreover, due to the quantum numbers of the initial and final two-nucleon states, it automatically eliminates the non-spin-flip component which is admixed with the spin-flip mode in the reactions initiated with half-integer-spin projectiles. The internal structure of the deuteron and diproton systems should be much simpler than those of heavier complex projectiles such as ${}^{12}\mathrm{C}$ and ${}^{14}\mathrm{N}$, which also satisfy these criteria.

The demonstrated feasibility[2] of detecting the unbound ${}^2\mathrm{He}$ system as a reaction product in the $(\alpha, {}^2\mathrm{He})$ reaction immediately suggests exploring the $(d, {}^2\mathrm{He})$ reaction as a spin-flip, charge-exchange probe. Such a study was carried out at $E_d = 55$ MeV on ${}^6\mathrm{Li}$, ${}^{10}\mathrm{B}$, and ${}^{12}\mathrm{C}$.[3] The results of this study were positive in that the observed cross sections were consistent with a direct, one-step charge-exchange mechanism. That is, the shapes and magnitudes of the measured angular distribution were reasonably well matched by a combination of distorted-wave Born approximation reaction-mechanism calculations and shell-model structure predictions. However, the angular distributions observed were not strikingly characteristic of particular angular momentum transfers and, in particular, the $\Delta L = 0$ transitions were neither noticeably enhanced in magnitude nor easily identifiable by virtue of their shape. The results of the 55 MeV study thus suggest that the $(d, {}^2\mathrm{He})$ reaction leading to known final states can yield valuable spectroscopic information about these states, but they do not demonstrate that this reaction can be successfully used as a probe of $\Delta S = 1$, $\Delta T = 1$ strength in a region of unknown structural features. To be successful in this latter mode, the reaction must supply a characteristic signature, such as a dominant cross section for $\Delta L = 0$ relative to other ΔL transfers or a combination of large cross sections and distinctive angular distribution.

Motivated by the hope that the $(d, {}^2\mathrm{He})$ reaction might be more selective in enhancing $\Delta L = 0$ spin-flip transitions at a higher bombarding energy, we have repeated the study of the ${}^{12}\mathrm{C}(d, {}^2\mathrm{He}){}^{12}\mathrm{B}$ reaction at 99 MeV. This particular reaction is convenient for the usual reasons concerning target fabrication, stability, etc., of ${}^{12}\mathrm{C}$ and its ground state spin of $J^\pi = 0^+$ and, more importantly, because the ground state of ${}^{12}\mathrm{B}$ has $J^\pi = 1^+$. Its structure is known [from inelastic electron scattering studies connecting the ground state of ${}^{12}\mathrm{C}$ to the $(J^\pi, T) = (1^+, 1)$ isobaric analog of the ${}^{12}\mathrm{B}$ ground state[4]] to have a large overlap with the ${}^{12}\mathrm{C}$ target via the $\Delta S = 1$, $\Delta T = 1$ operator. Hence, if the $(d, {}^2\mathrm{He})$ reaction at 99 MeV is to be useful as probe for discovering $\Delta S = 1$, $\Delta T = 1$ strength, the ${}^{12}\mathrm{B}$ ground state must unambiguously dominate the final state spectrum.

Our measurements employed a 99.2 MeV deuteron beam from the Indiana University Cyclotron Facility. Protons were detected in two solid state detector telescopes (450 μm of Si as ΔE, 15 mm Ge as E), each subtending a solid angle of 1.14 msr. The detectors were mounted in the same vertical plane with their centers 2.33° above and below, respectively, the hor-

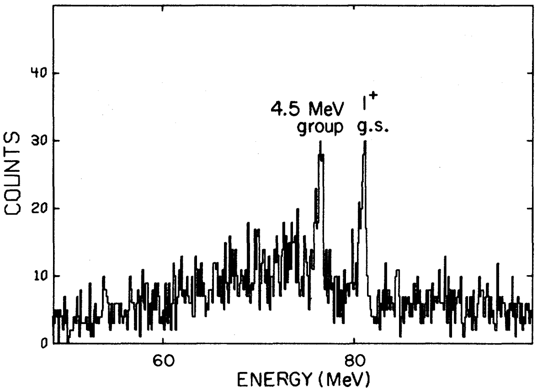

FIG. 1. ^{2}He energy spectrum from ^{12}C(d, ^{2}He)^{12}B reaction at $E_d = 99$ MeV.

izontal plane.

The signals corresponding to the total energy deposited in each telescope (E_1 and E_2), the sum of the energy in the two telescopes ($E_1 + E_2$), the particle identification from each telescope (PI_1 and PI_2), and the time-to-amplitude converter-generated time difference between the E_1 and E_2 signals were recorded. The coincidence energy spectrum ($E_1 + E_2$) for ^{12}C(d, ^{2}He)^{12}B at 99.2 MeV and $\theta_{\text{lab}} = 20°$ is shown in Fig. 1. Energy resolution is 480 keV full width at half maximum, and the calibration indicates that the two strong peaks correspond to the $J^\pi = 1^+$ ground state and 4.5 MeV ($J^\pi = 4^-, 2^-, 1^-$) group. In Fig. 2, the measured energy difference spectrum of the protons recorded in coincidence in the two detectors ($|E_1 - E_2|$) is compared to the predictions of Watson-Migdal theory[5] for the di-proton spectrum in our geometry. We take the correspondence as confirmation that our measurements do involve formation of a di-proton as the exit "particle."

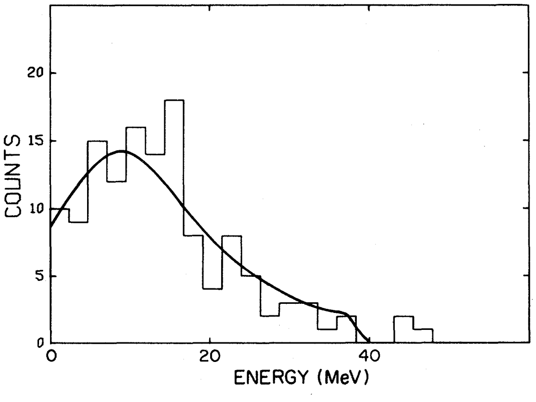

FIG. 2. Energy difference spectrum for the reaction ^{12}C(d, ^{2}He)^{12}B (g.s.) at $E_\alpha = 99$ MeV. The solid line is the result of the Watson-Migdal final state interaction calculation normalized to the data.

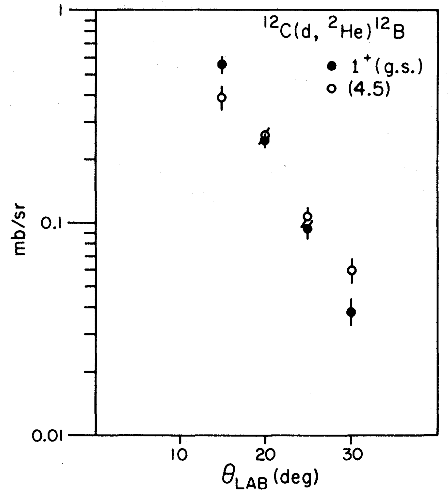

FIG. 3. Cross section vs angle for ^{12}C(d, ^{2}He)^{12}B at $E_d = 99$ MeV.

In Fig. 3, we show the angular distribution between 15 and 30° for the two strong peaks in the spectrum of Fig. 1. Both groups exhibit differential cross sections which decrease exponentially with increasing angle, the ground state group showing a steeper slope than the 4.5 MeV group.

Our results show little qualitative difference from those obtained at lower energy. The angular distributions at 99 MeV are more strongly forward peaked than at 55 MeV, and the strength of the ground state relative to that of the first excited 2^+ state appears (within our statistics for the $J^\pi = 2^+$ state) larger at the higher energy. The former observation suggests, of course, that measurements be extended to smaller angles in the hope that the cross sections of the $\Delta L = 0$ transition would be, as is usually the case, further enhanced nearer 0°. Unfortunately, the deuteron beam carries an intrinsic impediment to such measurements in the form of the breakup of the deuteron. The cross section for this process increases with energy and with the approach to 0°.[6]

The essential result of our measurements, however, is that the strength of the $J^\pi = 1^+$ ground state relative to that of the 4.5 MeV group is not qualitatively different at 99 MeV than it was at 55 MeV. Hence it does not appear feasible to use the (d, ^{2}He) reaction at 99 MeV, any more than at 55 MeV, to probe a region of excitation in which level densities are high and specific spin assignments lacking so as to identify $\Delta L = 0$, $\Delta S = 1$, $\Delta T = 1$ transitions and measure their strengths.

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