Interaction between D^2 and He^3 in the Neighborhood of the 18.6-Mev Level of Li^{5*}†

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The elastic-scattering differential cross sections and the cross section for the reaction $He^3(d,\alpha)H^1$ have been measured in the neighborhood of energies corresponding to the 18.6-Mev level in the compound nucleus Li^{5*}. The reaction data are essentially in agreement with earlier data having a maximum in the total cross section of approximately 0.94 barn. The interference between the elastic scattering and reaction process make the elastic-scattering cross sections at $\theta_{c.m.}=65.4°$ about 40 percent less than Rutherford scattering.

SEVERAL investigators have measured the cross sections for the reaction $He^3(d,p)He^4$ in the neighborhood of energies corresponding to the 18.6-Mev excited level in the compound nucleus Li^{5*}.[1–5] The more recent measurements of Lillie *et al.*,[3] and Yarnell *et al.*[5] give cross-section values which are in considerable disagreement near the resonance of the reaction. Both of these latter sets of reaction data have been taken with an electrically insulated gas cell connected to the target tube of an accelerator. This target of He^3 gas then served as a source of high-energy protons when bombarded with deuterons. The yield of these protons was then measured externally.

In the present experiment we used the small-volume scattering chamber described earlier[6] but modified it to support entrance, exit, and counter windows of 0.015-mil nickel[7] having a measured thickness of 65 kev for protons with 340 kev of energy. The procedure for taking data was quite similar to the procedure in reference 6 and will not be restated here. This apparatus allowed us to measure the yield of elastically scattered deuterons at small angles and the yield of reaction particles at any laboratory angle between 27° and 163°. We chose to measure the yield of elastically scattered deuterons at 40° as a function of energy as this was the most favorable angle to resolve the desired yields from contamination effects at all energies concerned. Pulses due to scattering from the 5.5 percent of He^4 in the gas could not be resolved and the data were corrected for this by assuming Rutherford scattering from the He^4. We chose to measure, in addition to the scattered deuterons, the yield of α particles from the reaction $He^3(d,p)He^4$ rather than the yield of protons, and these measurements were made at 163° in the laboratory.

The lower limit to the energy of the bombarding deuteron was determined by assuming that there was little charge exchange for deuterons passing through media while they had energies greater than the energy corresponding to the maximum of their dE/dx curve. Our experimental arrangement would then make measurements of the number of incident duterons by charge collection reliable to ±3 percent at energies greater than 375 kev at the center of the target chamber. This assumption was partially checked by comparing measured values of scattering from argon with calculated Rutherford values. The errors determined here as a function of pressure of the scattering gas and energy of the incident deuterons were consistent with an assumption that they were due to small angle scattering in the gas. The large change in Z in going from argon to helium would give a negligible small-angle scattering error in the case of deuterons scattered from helium.

The calibrations of the electrostatic generator were made at the threshold of the $Li^7(p,n)Be^7$[8] reaction and the 340.4-kev gamma-ray resonance of the reaction $F^{19}(p,\alpha\gamma)O^{16}$.[9,10] The energy loss in the nickel windows was determined by measuring the energy displacement

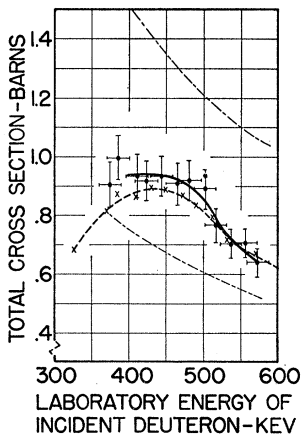

FIG. 1. Total center-of-mass cross sections for the reaction $He^3(d,\alpha)H^1$ as a function of energy. The ordinate values are 4π times the center-of-mass differential cross sections measured at 163° in the laboratory. The dashed line with crossed points shows the results of Yarnell *et al.* The lower and upper dashed lines are the calculated maxima values expected for the $l=0$, $S=\frac{1}{2}$ state and the $l=0$, $S=\frac{3}{2}$ state, respectively, of the D−He^3 wave function. The solid curve through the points is drawn from a best fit of the complex amplitude of the outgoing wave in the D−He^3 wave functions for the $l=0$, $S=\frac{3}{2}$ state.

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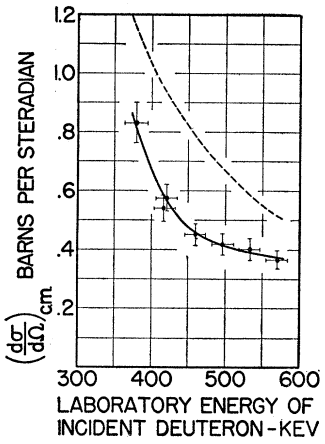

FIG. 2. Differential center-of-mass cross sections for the elastic scattering of deuterons from He^3 as a function of energy at θ cm $=65.4°$. The dashed curve shows the Rutherford scattering. The solid curve through the points is drawn from a best fit for the complex coefficient of the outgoing wave in the $D-He^3$ wave function for the $l=0$, $S=\frac{3}{2}$ state.

of the above gamma-ray resonance with and without a window in the path of the incident beam. The relative losses for deuterons at other energies were calculated with the aid of Kahn's dE/dx values[11] for copper. The energy loss in the gas was determined from the atomic stopping cross sections published by Weyl.[12] The largest contribution to the errors in energy was that the entrance-window thickness changed from 65 kev to 90 kev during the course of the experiment. A linear correction with respect to time was made for this change.

When all sources of error are considered, the measured values of the cross sections shown in Fig. 1 and Fig. 2 have errors of about ± 8 percent, and the knowledge of the energy for any given point is uncertain to ± 15 kev. The reaction data agrees with that of Yarnell *et al.* within experimental error. No angular distribution of the reaction data was made in this experiment, but we have used the spherical-symmetry property measured by Yarnell and multiplied center-of-mass differential cross section by 4π before plotting the total cross section shown in Fig. 1. These results are still consistent with the assignment of a $D_{\frac{3}{2}}$ state in Li^{5*}.

The elastic-scattering differential cross section is definitely less than Rutherford scattering for θ cm $=65.4°$. The two sets of data can be fitted with a complex coefficient for the outgoing wave in the $l=0$, $S=\frac{3}{2}$ state of the D^2-He^3 wave function. To analyze these data we followed the methods given by Blatt and Weisskopf.[13] The D^2-He^3 wave function, ψ, was found in terms of a superposition of the two spin states, $S=\frac{1}{2}$ and $S=\frac{3}{2}$, and then resolved into incoming and outgoing waves. To adjust for both reactions and scattering, a complex coefficient was given to the outgoing waves. With the assumption that nuclear interactions are short range, we concluded that only $l=0$ waves would contribute to nuclear effects at the energies used in this experiment. We also assumed that energy levels in the compound nucleus were sufficiently well isolated that only one of the spin states would contribute to the reaction. Then by properly normalizing the probability current associated with ψ and integrating this flux over the surface of a large sphere surrounding the region of the interaction, one can obtain an expression for the total cross section of the reaction. The maximum values of this total cross section for each of the spin states are shown in Fig. 1. If only one spin state is allowed, it then must be an $S=\frac{3}{2}$ state since the experimental values fall between these two maxima. The magnitude of the complex coefficient can be adjusted as a function of energy to obtain a best fit for the total reaction cross section. By subtracting the incident wave, ψ_{inc}, from the above ψ, one then has an expression for the scattered wave, ψ_{scatt}, which contains a phase shift which can be adjusted as a function of energy to fit the elastic-scattering data. The results of this best fit to the experimental data are shown by the solid curves in Fig. 1 and Fig. 2. Since the elastic-scattering data was obtained only at one scattering angle, the fits could not be subjected to further tests. However, the existence of these adjusted curves shows that the data is consistent with an assumption that the reaction results from an $l=0$, $S=\frac{3}{2}$ state.

We wish to extend our sincere thanks to the other members of the electrostatic generator group for help in obtaining these data.

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