The Scattering of Deuterons by Helium at Deuteron Energies from 0.9 to 3.5 Mev

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The differential cross sections for the elastic scattering of deuterons by helium have been measured for deuterons of 0.9 to 3.5 Mev over an angular range from 15° to 160° in the center-of-mass system. The probable error in the absolute values of the cross sections is 3 percent or less. For angles greater than 60° the cross sections are roughly independent of angle except at 3.5 Mev where they decrease with increasing angle up to 90° and increase beyond.

AS a continuation of our program of studying the scattering of various combinations of light nuclei[1–3] we have investigated the scattering of deuterons in helium for deuterons in the energy range of 0.9 to 3.5 Mev.

EXPERIMENTAL PROCEDURE

The same scattering chamber, counters, etc., were used in this work as the experiments on proton-proton[1] and deuteron-deuteron scattering[2] previously reported, except that the helium gas was admitted to the scattering chamber through a charcoal trap cooled with liquid nitrogen instead of through the palladium tube used for hydrogen and deuterium. The general procedure for taking data was the same as that described in reference 1, with the addition of background runs taken under normal operating conditions but with a small brass shutter moved in front of the counter slit system to prevent the entrance of scattered charged particles. The background counting rate observed in this was due mainly to recoil nuclei from the neutrons in the counter, and under proper operating conditions was only a few percent of the counting rate for scattered particles.

The electrostatic analyzer which controlled the energy of the incident deuterons was calibrated by means of the $Li^7(p,n)Be^7$ reaction, the threshold of which was taken to be 1.883 Mev. The effective thickness of the Nylon entrance window was measured both before and after the data were taken and at both times was found to be about 55 kv for 1.9-Mev protons. The energies were corrected for the energy losses in the windows and in the scattering gas between the window and the center of the chamber.**

Data were taken at various scattering angles from 10° to 90° in the laboratory system. For deuterons of energy 0.90 and 1.42 Mev the scattered deuterons would not pass through the counter window at angles larger than 30° and 60° respectively and the recoil helium atoms would not enter the counter at any angle. With incident deuterons of higher energy the deuterons could be observed to higher angles, up to 90° at 3.5 Mev; while at small angles the recoil helium atoms could be observed also. In most instances, where both sets of particles entered the counter, the helium atoms produced pulses which were sufficiently larger than those due to the deuterons so that the helium atoms could be counted separately by using a high bias setting on one of the pulse size discriminators. In a few cases the helium atoms had only enough energy to barely enter the counter and produce pulses smaller or so nearly the same size as the deuteron pulses that it was not possible to count the two separately.

The importance of counting the helium nuclei was that it provided a means of obtaining the cross section for deuteron scattering in the backward direction where the deuterons were not energetic enough to enter the counter. In this problem one does not have symmetry about 90° in the center of mass coordinate system, which is present in the proton-proton and deuteron-deuteron cases, so it was of interest to determine the scattering cross section to as large an angle as possible. Since to each deuteron which was scattered in the backward direction there corresponded a recoil helium in the forward direction one could obtain data for the backward directions by observing these recoil helium atoms in the cases where they had energy enough to enter the proportional counter. The cross section for scattering at 120° in the center-of-mass coordinate system, for example, was obtained from counting deuterons at 90° in the laboratory and also counting helium atoms at 30° in the laboratory.

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[1] Blair, Freier, Lampi, Sleator, and Williams, Phys. Rev. **74**, 553 (1948).
[2] Blair, Freier, Lampi, Sleator, and Williams, Phys. Rev. **74**, 1594 (1948).
[3] Freier, Lampi, Sleator, and Williams, Phys. Rev. **75**, 1345 (1949).
** In the papers on deuteron-deuteron scattering and on the *d-d* reactions referred to in references 2 and 4, an error was made in evaluating these corrections. The best values of the deuteron energies used in these two investigations are, in Mev, 0.87, 1.43, 1.96, 2.49, 3.02 and 3.52 instead of the values 0.96, 1.49, 2.01, 2.51, 3.02 and 3.50 Mev which are given in the tables of these papers.

For taking data at angles where the cross sections were relatively constant and the counting rates low, a proportional counter and analyzing slit system which were larger than those used for previous elastic scattering measurements were used. (This counter was the one used in the measurements on the distribution of the products of the deuteron-deuteron disintegrations.[4]) At points where data were taken with both counters the results agreed within the statistical fluctuations expected from the number of counts recorded.

Throughout the course of the experiment bias curves were taken at several different angles for each deuteron energy to determine the proper bias settings for counting the deuterons and recoil helium nuclei separately. During these surveys no evidence appeared for the presence of protons or neutrons from deuteron disintegration such as have been observed in deuteron helium experiments at higher energies.[5] This is in agreement with calculations which indicate that at the energies we used these disintegration products did not have enough energy to enter the proportional counter.

CORRECTIONS

In contrast to the previously reported observations on deuteron-deuteron scattering,[2] the observed data in this experiment required few corrections. The runs, mentioned above, which were taken with the shutter in front of the analyzer slits determined the small fraction of the counting rate which was caused by recoil atoms from neutrons produced by deuteron bombardments of defining apertures, chamber windows, etc.; and other counts not due to the scattered particles. The accumulation of contaminating gases in the scattering chamber was measured by closing the empty chamber and observing the increase in counting rate over a period of a few hours. It was found that the number of deuterons scattered from the gas which accumulated during this time increased linearly with time and had an angular distribution which agreed with the Coulomb scattering law. From this information one could make corrections to be observed data to eliminate the effect of such contamination. In most cases this correction amounted to less than one percent of the total counting rate.

In order to find out how completely the liquid nitrogen-cooled charcoal trap used in filling the chamber removed the one or two percent of other gases present in the tank helium, a sample of gas was taken from the chamber immediately after filling and analyzed on one of Dr. A. O. C. Nier's mass spectrometers. This test indicated that the helium as it entered the chamber contained about 0.08 percent air nuclei. A correction to be applied to the observed cross sections was calculated from this on the assumption of Coulomb scattering by the air. It amounted to about 1.4 percent at most, and was negligible above 40°.

The presence of about 0.3 percent HH^+ ions in the deuteron beam[2] called for a correction to the beam current measurement, and also a correction for the beam protons scattered into the counter at each angle. However, since these effects were both small and tended to cancel each other, they were ignored.

The corrections due to the finite size of the incident beam of deuterons and of the angular aperture of the proportional counter ("second order geometry" corrections) were computed for us by Mr. Donald Dodder, applying the method used previously.[1] In the present case the scattering cross section at small angles were sufficiently close to the corresponding Coulomb cross sections so that a reasonably accurate determination of the corrections could be made on the assumption of pure Coulomb scattering. This assumption yields corrections which are independent of energy and have the following magnitudes: 2.9 percent at 10° (laboratory system), 1.3 percent at 15°, 0.7 percent at 20°, 0.4 percent at 25° and 0.3 percent at 30°. At larger angles the Coulomb assumption is not adequate, but the corrections certainly decrease as the cross-section curves become straighter and flatter.

RESULTS

The cross sections per unit solid angle in the center-of-mass coordinate system for the scattering of deuterons by helium are given in Table I and Fig. 1. The values for scattering in the forward direction, ϕ_{cm} less than 110°, were obtained from observing the scattered deuterons, while those for backward directions were deduced from counts of

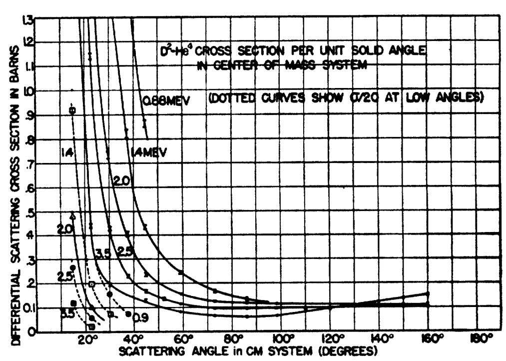

FIG. 1. Cross sections per unit solid angle in the center-of-mass coordinate system for the scattering of deuterons of various energies by helium. The dotted curves represent the same data on a scale reduced by a factor of twenty.

[4] Blair, Freier, Lampi, Sleator, and Williams, Phys. Rev. **74**, 1599 (1948).

[5] Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. **190**, 196 (1947).

TABLE I. Cross sections in the center-of-mass coordinate system for the elastic scattering of deuterons by helium. Deuteron energies are given in the laboratory system, and cross sections are in barns (10^{-24} cm^2).

ϕ_{cm}/E_d	0.88 Mev	1.43 Mev	1.96 Mev	2.48 Mev	3.51 Mev
15° 11′	50.0 ±0.4	18.27 ±0.2	9.45 ±0.10	5.32 ±0.05	2.40 ±0.02
22° 39′	9.66 ±0.10	3.96 ±0.04	1.961±0.02	1.128±0.010	0.436 ±0.008
30° 5′	3.21 ±0.04	1.474±0.02	0.729±0.015	0.423±0.007	0.193 ±0.003
37° 27′	1.484±0.02	0.819±0.015	0.403±0.008	0.227±0.004	
44° 45′	0.856±0.016	0.432±0.008	0.234±0.006	0.167±0.003	0.128 ±0.005
51° 57′				0.135±0.004	
59° 2′		0.244±0.005	0.150±0.003	0.119±0.003	0.083 ±0.002
72° 50′		0.167±0.004	0.122±0.003	0.096±0.002	0.0654±0.0015
85° 59′		0.137±0.003	0.114±0.003	0.095±0.002	0.0585±0.0012
98° 22′			0.109±0.002	0.092±0.002	0.0638±0.0020
110°				0.090±0.002	
120°				0.095±0.0016	0.093 ±0.002
130°			0.102±0.003	0.101±0.002	
140°				0.103±0.002	0.123 ±0.002
150°			0.107±0.002	0.101±0.002	0.141 ±0.002
160°			0.112±0.002	0.107±0.002	0.151 ±0.003

the recoil helium atoms. At 2.5-Mev measurements of the 120° and 130° cross sections by both methods agreed within the probable errors, and at the other energies the two sets of data overlapped smoothly when converted to the center of mass system, indicating the absence of significant errors in geometry. The factors for conversion from laboratory to center-of-mass coordinates were obtained as outlined in reference 3. The probable errors given in the table are those expected from the number of counts recorded at each point. In addition there is a probable error of about 1.7 percent common to all points due to uncertainties in the factors involved in converting the original data into cross sections. The over-all probable error in most of the cross sections is about 3 percent.

The energies at the top of the columns apply to the deuterons in the laboratory system at the center of the chamber, and are accurate in absolute value to about ±20 kv.

Here, as in other charged particle scattering experiments, Coulomb scattering is predominant at the low angles: for example at 1.42 Mev and 30° 5′ the observed cross section differs from the Coulomb by about 14 percent. At higher energies nuclear scattering is relatively more important at the small angles, and completely dominates at the large. At 2.5 and 3.5 Mev the cross section increases with angle above 90°. This effect here, however, is quite small compared to the corresponding one in proton-deuteron scattering.[6] The rather sharp bend in the 3.5-Mev curve at about 25° and the crossing of the curves by each other is suggestive of proton-helium scattering and markedly different from the deuteron-deuteron results. However, the deuteron-helium cross sections are considerably more regular in both energy and angular dependence than are those for protons on helium where an energy resonance is apparent from qualitative examination of the curves.

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[6] Sherr, Blair, Kratz, Bailey, and Taschek, Phys. Rev. **72**, 662 (1947).