Elastic Scattering of Deuterons by He^3†

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Differential cross sections for the elastic scattering of deuterons by He^3 have been measured at laboratory energies of 1.02, 1.50, 2.00, 2.50, 3.00, and 3.25 Mev for nine center-of-mass angles ranging from 45° to 125°. At each deuteron energy the cross section passes through a minimum in the vicinity of 90°, with the minimum shifting to slightly higher angles as the bombarding energy increases. The cross section decreases with increasing energy for each angle investigated. At 3.25 Mev the cross section passes through a minimum of 16 millibarns at 100° and rises to approximately 80 millibarns at 45° and 125°. A comparison of the results for the scattering of deuterons by He^3 and by the mirror nucleus H^3 shows the cross sections to be approximately the same except at the lowest energies and forward angles.

INTRODUCTION

MEASUREMENTS of differential cross sections for elastic scattering between pairs of light nuclei have been extended to include the scattering of deuterons by He^3. Data were taken for deuterons scattered at center-of-mass angles from 45° to 125° at laboratory bombarding energies from 1.02 Mev to 3.25 Mev.

Differential cross sections have been previously measured[1] in the above angle and energy range for the scattering of deuterons by H^3, the mirror nucleus of He^3, and results will be compared with those of the present experiment. In an earlier experiment[2] measurements of differential cross sections were made for the scattering of 10-Mev deuterons by He^3 and by H^3 with nearly identical results for the two scattering processes.

EQUIPMENT

The small volume scattering chamber employed in the present experiment was the one used for the scattering of protons by deuterons and is described by Brown *et al.*[3] A minor modification was made in the slit system defining the scattered beam to prevent high-energy protons due to the $He^3(d,p)He^4$ reaction from penetrating the original 6-mil tantalum slit material and entering the counter with reduced energy. The circular aperture next to the counter was replaced by one cut from 20-mil gold sheet. The original rectangular tantalum slits were backed by 20-mil gold strips. The aperture in the gold material was slightly wider than that in the tantalum, so that particles could not strike the gold slit edges without first penetrating the tantalum.

The beam entering the chamber was collimated to within a half-angle of 1.1°, while the defining slit system for the scattered beam permitted an rms angular deviation of 0.6° from the nominal laboratory scattering angle.

The electrical current carried by the deuteron beam was measured and integrated by an electronic instrument[4] instead of by the condenser and ballistic galvanometer system described in reference 3. After collecting a predetermined electrical charge, the instrument stopped the counters and placed a shutter in the path of the deuteron beam.

Scattered particles were detected in a proportional counter, and pulse-height distributions were recorded by a ten-channel discriminator[5] in the manner described in reference 3.

He^3 HANDLING

The He^3 handling system was adapted from the one previously described in connection with the study of the proton yield from the $He^3(d,p)He^4$ reaction.[6] The He^3 was stored and purified in a glass bulb containing activated charcoal and was transferred between the storage bulb and the scattering chamber by means of a mercury Toepler pump. To keep mercury and condensable vapors from passing into the scattering chamber, a liquid nitrogen trap was placed in the line from the He^3 handling system to the chamber.

The amount of He^4 impurity in the He^3 was measured at intervals by the mass spectrometer group at the University of Minnesota and was found to be 5.5 percent by volume. Over a period of about ten months this concentration was constant within the accuracy of the measurements, about 0.3 percent.

The pressure in the chamber was indicated by a Wallace and Tiernan differential manometer as in the experiment described in reference 3. A gradual rise in pressure of the order of 0.5 mm Hg (with a chamber pressure of about 40 mm Hg) was observed when data were taken over a period of several hours; the rise was

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[1] Stratton, Freier, Keepin, Rankin, and Stratton, Phys. Rev. 88, 257 (1952).
[2] Allred, Armstrong, Hudson, Potter, Robinson, Rosen, and Stovall, Phys. Rev. 88, 425 (1952).
[3] Brown, Freier, Holmgren, Stratton, and Yarnell, Phys. Rev. 88, 253 (1952).
[4] R. J. S. Brown, Rev. Sci. Instr. (to be published).
[5] W. C. Elmore and M. Sands, *Electronics* (McGraw-Hill Book Company, Inc., New York, 1949).
[6] Yarnell, Lovberg, and Stratton, Phys. Rev. 90, 292 (1953).

attributed to materials outgassing from the chamber walls. The effect of the pressure rise on the data was determined by repeating runs after the gas had been in the chamber for different lengths of time. In most cases it was necessary to repurify the gas after about three hours of use.

IDENTIFICATION OF PARTICLES

There were six groups of charged particles which entered the proportional counter when the mixture of He^3 and He^4 was bombarded with deuterons: deuterons scattered by He^3 and by the He^4 impurity, the He^3 and the He^4 recoil nuclei, and protons and alpha particles from the $He^3(d,p)He^4$ reaction. At each bombarding energy and angle of observation, the energies of the particles were computed and their ionization losses in the counter gas determined from known energy-loss relations.[7] The particle groups could then be identified by the magnitudes of the pulses which they produced in the proportional counter.

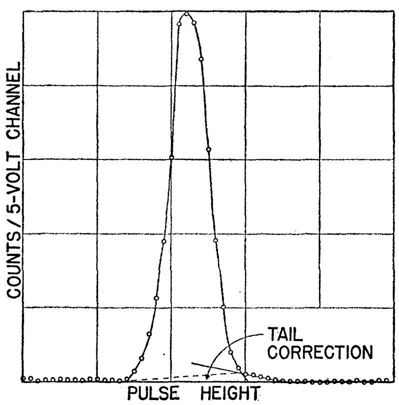

FIG. 1. Pulse-height distribution from 1.02-Mev deuterons scattered from He^3 at 27° (lab).

At most angles and energies, pulses from deuterons scattered by He^3 were not resolved from those due to deuterons scattered by He^4. In addition, it was seldom possible to separate the pulses produced by the recoil He^3 nuclei from those produced by the recoil He^4 nuclei. Pulses from the scattered deuterons were always resolved from those due to the recoil nuclei. The known amount of He^4 in the He^3 contributed counts which could be subtracted, since the cross sections for the elastic scattering of deuterons by He^4 were known.[8] Alpha-particle pulses from the $He^3(d,p)He^4$ reaction were resolved from those due to all other particle groups except at the bombarding energy of 1.02 Mev. Since the cross sections for this reaction were known,[6] counts due to the alpha particles could be subtracted when necessary. The high energy protons from this reaction had such small energy loss in the counter that they were not observed.

[7] M. Livingston and H. A. Bethe, Revs. Modern Phys. **9**, 270 (1937).
[8] Blair, Freier, Lampi, and Sleator, Phys. Rev. **75**, 1678 (1949).

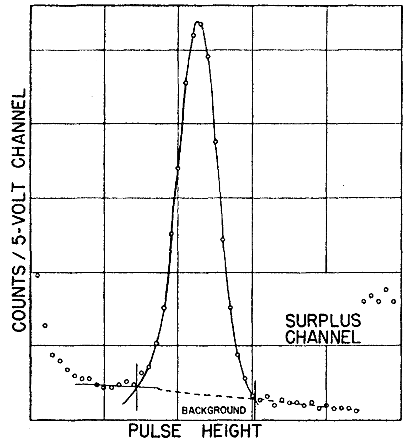

FIG. 2. Pulse-height distribution from 3.25-Mev deuterons scattered from He^3 at 50° (lab).

CORRECTIONS TO THE DATA

In previous work with the small volume scattering chamber,[1,3,9] it was found necessary to make corrections of the order of a few percent to the data taken at small angles. This correction subtracted counts due to particles which entered the counter after they had been doubly scattered, once by the gas and then again by the walls of the chamber.

Figure 1 shows a pulse-height distribution for d-He^3 scattering at a laboratory angle of 27° and a bombarding energy of 1.02 Mev. The tail on the high-pulse side of the peak is due to particles which have been scattered more than once. Counts of similar origin but appearing under the main peak are considered to be represented by the dashed line. The area under this line is subtracted from the peak.

The validity of this correction procedure was verified by applying it to the data obtained from scattering processes for which the cross sections were known from measurements with larger scattering chambers. Pulse-height distributions were taken for proton-proton scattering at representative angles and energies in the range of laboratory angles from 27° to 60° and energies from 1.5 Mev to 3.0 Mev. The data agreed within three percent of the accepted values[10,11] when corrected by the procedure followed for the d-He^3 scattering. Similar agreement was obtained from p-He^4 scattering[12] at 2.53 Mev for laboratory angles extending from 30° to 160°.

The incident deuteron beam produced neutrons at the collimating slits of the chamber. On the small volume chamber this source of neutrons was close to the counter, particularly when the counter was set at large angles. Figure 2 shows a pulse-height distribution in

[9] Claassen, Brown, Freier, and Stratton, Phys. Rev. **82**, 589 (1951).
[10] Herb, Kerst, Parkinson, and Plain, Phys. Rev. **55**, 998 (1939).
[11] Blair, Freier, Lampi, Sleator, and Williams, Phys. Rev. **74**, 553 (1948).
[12] Freier, Lampi, Sleator, and Williams, Phys. Rev. **75**, 1345 (1949).

TABLE I. Elastic scattering of deuterons by He^3. θ is the center-of-mass angle; $\sigma(\theta)$ is the center-of-mass differential cross section. For each angle and energy the uppermost number is $\sigma(\theta)$ in millibarns; the middle number is $k^2\sigma(\theta)$ (dimensionless); the lowest number is the estimated probable error in percent.

Scattering angle		Deuteron energy (lab)					
Lab angle	C.m. angle	1.02 Mev	1.5 Mev	2.0 Mev	2.5 Mev	3.0 Mev	3.25 Mev
27° 22′	45° 15′	406	216	128	102	80.9	77
		1.44	1.13	0.87	0.88	0.843	0.87
		6%	4%	4%	3%	3%	4%
33° 15′	54° 44′	226	130	82	65	55.8	55
		0.80	0.68	0.57	0.56	0.581	0.62
		4%	4%	4%	3%	3%	6%
40°	65° 25′		98	59	45.4	38.2	38.6
			0.51	0.41	0.394	0.398	0.435
			4%	4%	4%	4%	6%
45°	73° 11′		81	55	41.3	32.2	28.8
			0.42	0.38	0.358	0.335	0.325
			4%	4%	4%	4%	5%
50°	80° 46′		80	50	36	23.3	22.2
			0.42	0.35	0.31	0.243	0.250
			4%	4%	5%	5%	6%
56° 15′	90°		85	52	34	21.1	17.3
			0.44	0.36	0.29	0.220	0.195
			5%	5%	5%	6%	7%
62° 23′	98° 39′					20.5	16.0
						0.213	0.180
						8%	7%
70°	108° 52′		115	82	54.9	31.5	24.0
			0.60	0.57	0.476	0.328	0.271
			8%	4%	3%	5%	7%
83° 41′	125° 16′		155	126	106	89.3	84.8
			0.80	0.87	0.92	0.930	0.957
			5%	4%	3%	3%	3%

which the neutron background was high and the d-He^3 cross section was relatively small. The background, which was subtracted, is indicated by the dashed line.

ERRORS

Probable errors assigned to the following factors in the experiment are: correction for He^4 impurity in the He^3, 0.5 percent; geometry (including angle of scattering), 0.7 percent; charge measurement, 0.5 percent; pressure and temperature measurement, negligible; statistics, 1.0 percent or less; bombarding energy, 1.2 percent or less. If these errors are combined quadratically, the result is less than 2 percent.

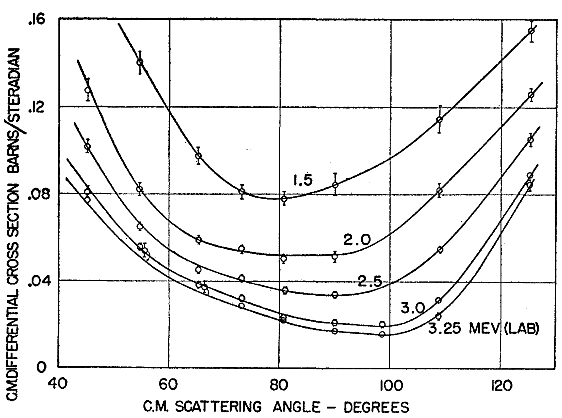

FIG. 3. Center-of-mass differential cross sections for the scattering of deuterons by He^3.

Since the estimated errors of the background corrections are several times as great as those from all other sources, the error which is assigned to each cross-section measurement is, in most cases, the estimated uncertainty of the background subtraction. In all cases, the assigned error is greater than the root-mean-square deviation of the individual measurements from their means, and greater than fifteen percent of the background correction.

RESULTS

The results are tabulated in Table I and shown graphically in Fig. 3. No distinction is made between values of cross sections obtained by detection of recoil and of directly scattered particles. Values obtained by the two methods agreed well within the assigned probable errors in cases where both direct and recoil data were taken.

The function $k^2\sigma(\theta)$ is tabulated, with k equal to the center-of-mass momentum divided by $\hbar$.

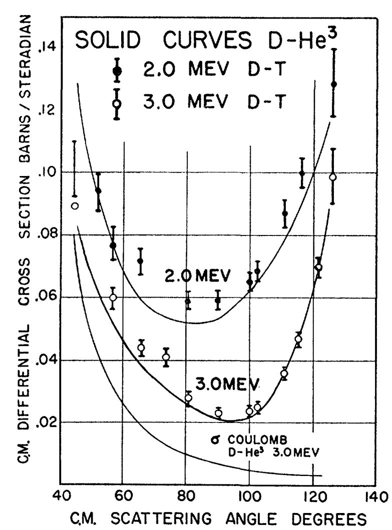

FIG. 4. Comparison of cross sections for the scattering of deuterons by He^3 and by H^3. The solid curve is the d-He^3 Coulomb cross section, calculated from the Rutherford formula.

In Fig. 4 the cross sections for the scattering of deuterons by H^3 and He^3 are compared. In addition, the Coulomb cross sections calculated from the Rutherford formula are shown. It is seen that the d-He^3 and d-H^3 scattering cross sections are essentially the same at large angles and high energies, where the Coulomb cross sections are small. At 10.0 Mev Allred *et al.*[2] found essentially the same cross sections for the two scatterings except at low angles, where the Coulomb cross sections are appreciable.

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