Elastic Scattering of 21.0-MeV Deuterons by He^4†

H. W. Broek* and J. L. Yntema
Argonne National Laboratory, Argonne, Illinois
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The elastic scattering of 21.0-MeV deuterons by He^4 has been measured from 16° to 166°. The absolute differential cross sections are tabulated. The data show no indication for the relative maximum found near 60° at 24.85 MeV by Van Oers and Brockman. However, the cross section at the minimum near 55° is larger than the one obtained previously at lower energies.

INTRODUCTION

RECENTLY, some new experiments on the elastic scattering of deuterons by He^4 have been reported.[1–3] The data obtained by Van Oers and Brockman[2] at an incident-deuteron energy of 24.85 MeV show the appearance of a new relative maximum near 60° c.m. They measured the cross section at 60° c.m. at a number of energies down to approximately 21.6 MeV and observed a slight decrease in absolute cross section. However, the cross section at 21.6 MeV was approximately 40% higher than the ones reported previously at 20.2[4] and 19.0 MeV.[5] They also observed that the increase in cross section at large angles was considerably less than the one previously reported at the lower energies. A repetition[1] of the experiment at 13.7 MeV showed a considerably smaller increase at backward angles than was observed in a previous experiment at the same energy, reported simultaneously with the 19.0-MeV data. On this basis it appeared desirable to measure the elastic-scattering cross section over as wide an angular range as practicable at 21.0 MeV. After the completion of this experiment, a paper containing angular distributions at energies of 27.3, 25.8, 24.3, and 21.3 MeV was published.[3] In this paper the new relative maximum near 60° appears to be considerably less pronounced at 24.3 MeV than at 24.85 MeV and the cross section is more than 10% below the one observed by Van Oers and Brockman while the minimum near 50° c.m. is considerably deeper. The angular distribution at angles between 40° and 80° in the 21.3-MeV data appears to be less smooth than one would expect on the basis of the data previously reported at 19.0 and 20.2 MeV.

EXPERIMENTAL PROCEDURE

The experiment was performed with the external beam of the Argonne 60-in. cyclotron. In order not to fill the entire 60-in. scattering[6] chamber with the gas, a gas container was located in the 60-in. chamber. The container is held in a fixed position with respect to the collimator and is separated from the beam tube and the scattering chamber by means of 0.00025-in. Permalloy foils. The foils are located along the circumference of the chamber in such a way that scattered particles can be observed at all angles between 0 and 170°. The container encloses the collimating system for the scattered beam. This system is rigidly tied to the movable arm of the 60-in. chamber. The mean angle of scattering can therefore be measured to ±0.1°. The defining apertures of the system consisted of two rectangular slits.[7] These slits had a width of 0.0600 in. and a height of 0.3000 in. The face of the rear slit was at a distance of

$$14.500_{-0.000}^{+0.001} \text{ in.}$$

from the center of scattering. The distance between the front faces of the two slits was

$$8.753_{-0.000}^{+0.001} \text{ in.}$$

The detector assembly consisted of a 0.008-in.-thick silicon surface-barrier detector followed by either a NaI(Tl) crystal or a Li-drifted silicon detector. The gas pressure was measured with a mercury manometer read through a calibrated cathetometer. It was assumed that the gas was in thermal equilibrium with the walls of the container. The temperature of the 60-in. chamber was measured with a calibrated thermometer. It can be shown that in the center of the container the temperature rise due to the deuteron beam is negligible.

The relative linewidth of the NaI(Tl) detector was about 1.5% (full width at half-maximum) for full-energy deuterons. The spectra obtained at a number of angles indicate that the contamination of the gas was at all times less than 1%. The deuterons were identified by means of a pulse-multiplier circuit which was adjusted to give a constant pulse height for deuterons

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* Present address: Bell Telephone Laboratories, Whippany, New Jersey.
[1] Leona Stewart, J. E. Brolley, Jr., and L. Rosen, Phys. Rev. 128, 707 (1962).
[2] W. T. H. Van Oers and K. W. Brockman, Jr., Nucl. Phys. 44, 546 (1963).
[3] H. J. Erramuspe and R. J. Slobodrian, Nucl. Phys. 49, 65 (1963).
[4] K. P. Artemov and N. A. Vlasov, Zh. Eksperim. i Teor. Fiz. 39, 1612 (1960) [English transl.: Soviet Phys.—JETP 12, 1124 (1961)].
[5] R. G. Freemantle, T. Grotdal, W. M. Gibson, R. McKeague, D. J. Prowse, and J. Rotblat, Phil. Mag. 45, 1090 (1954).
[6] J. L. Yntema and H. W. Ostrander, Nucl. Instr. Methods 16, 69 (1962).
[7] H. R. Worthington, J. N. McGruer, and D. E. Findley, Phys. Rev. 90, 899 (1953).

TABLE I. Cross sections for the scattering of 21.0-MeV deuterons by helium. The second point at 87.8° and all subsequent points were obtained from the α recoil.

$\theta_{c.m.}$	$d\sigma/d\omega$ (mb/sr)	Rms error (%)	$\theta_{c.m.}$	$d\sigma/d\omega$ (mb/sr)	Rms errors (%)
16.6	633	3	85.9	30.7	4
18.1	578	3	87.8	30.9	4
19.6	515	4	87.8	30.1*	5
21.0	447	3	89.8	30.3	5
22.5	403	3	91.8	28.9	4
24.0	366	3	93.8	29.2	5
24.8	332	3	95.8	28.4	5
27.0	273	3	97.8	28.5	5
28.5	237	3	99.8	29.4	5
30.0	199.3	3	101.8	30.0	5
31.5	166	3	103.8	28.5	4
32.9	138.4	3	105.8	27.5	5
34.4	114	3	107.8	27.0	5
35.9	94	3	109.8	25.9	4
37.4	76	3	111.8	24.8	5
38.8	65.6	3	113.8	23.2	5
40.3	52.0	3	115.8	21.7	5
41.8	43.6	3	117.8	20.2	6
43.2	36.9	3.5	123.8	15.0	6
46.1	27.5	4	125.8	14.0	6
47.6	25.4	4	127.8	13.3	6
49.0	25.2	4	128.8	12.2	5
51.9	23.7	4	131.8	12.0	6
54.7	23.0	4	133.8	11.7	5
56.9	22.9	4	135.8	11.2	5
57.6	24.7	4	137.8	11.0	6
58.7	24.1	4	139.8	11.0	7
60.4	24.2	4	141.8	11.1	7
61.8	25.5	4	143.8	11.4	7
64.6	27.0	4	145.8	12.0	7
67.3	28.6	4	147.9	12.3	7
70.0	28.4	4	149.9	12.8	8
72.1	28.8	4	151.9	14.4	8
73.4	30.4	4	153.9	13.9	8
75.4	30.2	4	155.9	15.4	8
76.8	29.6	4	157.8	16.6	8
78.8	30.9	4	161.9	18.0	10
80.1	29.7	4	163.9	18.9	7
82.0	30.5	4	165.9	20.8	6
84.0	30.7	4			

by use of the mechanism described by O'Neill *et al.*[8] The data have not been corrected for reactions between the deuterons and the NaI(Tl) crystal. It is clear that some loss due to such reactions does occur.

The scattering cross section was obtained from the elastically scattered deuterons between 16° c.m. and 85° c.m. and from 85° c.m. to 165° c.m. from observation of the recoil α particles.

The energy of the beam was measured with the device described by Ramler[9] and was determined to be 21.0±0.1 MeV at the center of the scattering chamber.

[8] W. J. O'Neill, E. Sundahl, and H. Ostrander, Nucl. Instr. Methods 4, 50 (1959).

[9] W. Ramler, J. L. Yntema, and M. C. Oselka, Nucl. Instr. Methods 8, 217 (1960).

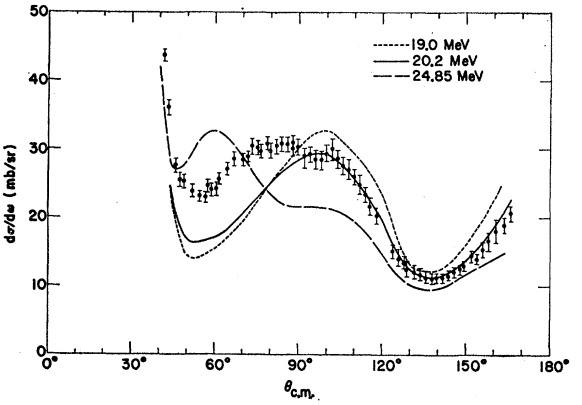

FIG. 1. Differential cross sections in the center-of-mass system for the elastic scattering of deuterons by He^4 at several energies. The experimental points show the results of the present work at 21.0 MeV.

EXPERIMENTAL RESULTS

The experimental cross sections are tabulated in Table I. A computer program reduced the data to cross sections in the center-of-mass system. The relativistic effects were taken into account. The rms error listed takes into account the statistical uncertainty from the number of counts, the uncertainty in the background subtraction, and the uncertainty in the measurement of the gas density.

The angular distribution from 40 to 166° is shown in Fig. 1 together with the ones obtained at 24.85 MeV,[2] 20.2 MeV,[4] and 19.0 MeV.[5] Comparison of the present work with the 19.0- and 20.2-MeV data shows that at 21 MeV the minimum near 50° is much less pronounced than previously observed while the maximum near 90° has become broader and flatter though it retains approximately the same cross section near its maximum as at 19.0 MeV. The minimum near 140° is about the same as at 19.0 MeV and the increase in cross section is much less pronounced.

A rather inaccurate comparison with the 21.3-MeV data seems to indicate that the minimum near 140° is about 20% lower and the minimum near 55° about 15% higher in the present data.

The protons from the $He^4(d,p)He^5$ reaction were observed at a number of angles. The observed cross sections were in fair agreement with the ones reported in Ref. 3 at 24.3 MeV and in Ref. 4 at 20.2 MeV. A maximum in the angular distribution was observed at 9.5° where the cross section is 87±5 mb/sr. The cross section at 22° was 43±3 mb/sr.

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