Angular Distribution of 1- to 3.5-Mev Protons Scattered by He^4

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The angular distribution of protons scattered by He^4 has been measured in the energy range from 1 to 3.5 Mev and over an angular range of 10° to 164° in the laboratory. The results are given as absolute cross sections per unit solid angle and show a broad resonance at approximately 2.2 Mev. The values for the cross sections are considered to be reliable to ±3 percent.

INTRODUCTION

THE scattering of protons by helium has been investigated by other groups interested in establishing the existence of resonance scattering similar to that originally found in neutron-helium scattering by Staub and Stephens.[1] The reaction investigated in $p-$He scattering is

$$H^1+He^4 \rightarrow Li^{*5} \rightarrow H^1+He^4,$$

where an excited state of the compound nucleus gives rise to resonance scattering.

The most extensive proton-helium scattering data up to the present time have been obtained by Heydenburg and Ramsey[2] where measurements were taken from 1 Mev to 3 Mev for the incident proton energies and over angles of 20° to 140° in the laboratory. Previous proton-helium scattering experiments were done by Roberts and Heydenburg[3] for incident protons up to 1 Mev. Experiments on the scattering of α-particles by hydrogen have been done by several workers.[4] By using α-particles up to 8.5 Mev they could obtain data corresponding to a maximum incident proton energy of 2.1 Mev. The present experiment extends the proton energy range to 3.5 Mev and extends the angular measurements down to 10° and up to 164° in the laboratory system of coordinates. These more complete data have made it possible to determine more exactly the shape of the differential cross-section curves.

EXPERIMENTAL PROCEDURE

The same apparatus was used in this work as in the experiments on proton-proton scattering[5] and deuteron-deuteron scattering.[6] The scattering chamber was filled with helium gas purified by storing it in a charcoal trap cooled with liquid nitrogen before letting it into the evacuated chamber. The number of scattering centers per cm^3 was determined by assuming the He^4 to be a perfect gas, measuring the pressure with an oil manometer, and measuring the temperature with a thermometer in equilibrium with the walls of the chamber. The total number of scattering centers was then determined by the volume common to the collimated incident beam and the imaginary column extending beyond and defined by the slit system of the counter. Pressures of approximately 1 cm of Hg were used in the chamber and were found to give no measurable multiple scattering in the gas.

The number of incident particles was measured by collecting them in a Faraday cage at the exit end of the chamber. The collector was in turn connected to a calibrated condenser and ballistic galvanometer system.

The number of scattered protons was measured with a proportional counter which rotated about a central axis through the small scattering volume described above. The factors for obtaining the differential cross section from the number of scattered particles were the same as in previous work.[5]

At low angles and high energies the recoil He^4 nuclei entered the proportional counter as well as the scattered protons. In general the He^4 pulses could be differentiated from the proton pulses by proper selection of bias voltages on the discriminator-scaler units. A typical bias curve is shown in Fig. 1. One discriminator set on the plateau A counted all the pulses, while the second set on plateau B counted only He^4 pulses. The number of protons scattered into the counter during any one

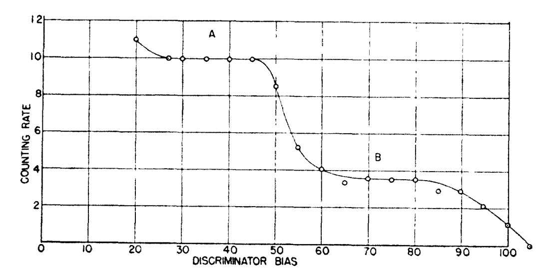

FIG. 1. Typical curve of the counting rate as a function of the discriminator bias showing the relative size of the scattered proton pulses and recoil helium pulses which entered the proportional counter.

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TABLE I. Proton-helium scattering cross sections per unit solid angle in the center of mass coordinate system as a function of the proton energy in the laboratory and the scattering angle in the center of mass system of coordinates. Cross sections are in barns (10^{-24} cm^2). Proton energies are in Mev. The starred values are obtained from measurements with recoil helium atoms.

φ/E_p	0.95	1.49	1.70	2.02	2.22	2.53	3.04	3.58
12° 38′	62.8	22.9	15.92	9.97	8.12	6.46	5.32	4.33
18° 52′	12.35	4.05	2.50	1.564	1.405	1.500	1.520	1.348
25° 3′	4.04	1.090	0.654	0.496	0.600	0.823	0.921	0.834
31° 13′	1.713			0.291	0.441		0.728	
37° 20′	0.854	0.196	0.1461	0.271	0.398	0.554		0.554
43° 23′						0.502	0.523	0.481
49° 23′	0.322	0.1031	0.1057		0.331	0.474		
55° 21′							0.410	0.360
61° 10′	0.1735	0.0812	0.0940	0.1878		0.340		
66° 54′					0.238			
72° 37′	0.1217	0.0764		0.1540		0.253	0.246	0.224
90° 7′	0.0921	0.0828	0.0942	0.1262	0.1487			0.1390
94° 22′						0.1507	0.1408	
99° 28′	0.0833							
104° 36′				0.1402				
110° 14′								0.0997*
114° 22′		0.1202	0.1502	0.1795	0.1830	0.1740	0.1265	0.0985
120° 14′								0.0981*
132° 37′		0.1692	0.219	0.279	0.287	0.260	0.1710	0.1200
140° 14′							0.1950*	0.1428*
149° 22′		0.205	0.270	0.372	0.386	0.353	0.232	0.1663
150° 14′						0.345*	0.226*	0.1621*
160° 14′						0.407*	0.273*	0.1915*
164° 59′							0.280	
168° 2′			0.311	0.443	0.475	0.433	0.281	0.1935

run was the difference of the readings on these two scalers. At some angle and energy combinations the protons and recoil He^4 gave the same sized pulses. To obtain these data on the number of scattered protons an aluminum window which stopped the He^4 nuclei, but not the protons, was placed in front of the proportional counter. At the other angles the data from the recoil He^4 counts was used to calculate the differential cross sections of protons scattered in a backward direction and served as a check on direct measurements of protons scattered in a backward direction.

Measurements of the background counting rate were made by rotating a small brass shutter in front of the slit system of the counter. The number of background counts was in general only a fraction of a percent of the number of counts measured during a run. Enough runs were taken to get a total of at least 3000 counts at any one angle and energy.

The energy scale was calibrated on the basis of 1.882 Mev for the threshold of the $Li^7(p,n)Be^7$ reaction. The energies given are good to ± 20 kv.

CORRECTIONS

The observed number of counts was subject to some corrections. After the chamber was closed from the pumps, it would still outgas and con-

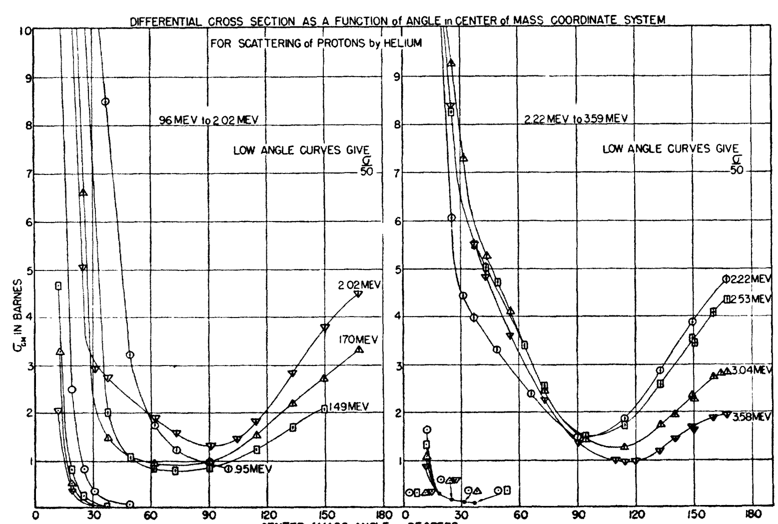

FIG. 2. Proton-helium scattering cross sections per unit solid angle in the center of mass coordinate system for various proton energies in the laboratory system of coordinates. The curves at small angles are reduced by a factor of 50.

taminate the scattering volume with some foreign gas. The time rate of accumulating contamination gases was measured by evacuating the chamber, closing the connection to the pumping system, and then counting the number of scattered protons at various small angles during a period of an hour or more. This value was found to be the linear function of the time for any given energy and angle and was used to correct the data at other angles and energies by assuming a Coulomb scattering law. A check on this correction was made by comparing data taken immediately after filling the chamber with data requiring up to a 4 percent contamination correction. Agreement was good to within statistical errors at the several angles and energies tested.

A second correction was made for residual air in the helium gas after purifaction. A sample of gas taken from the chamber immediately after filling and analyzed for us on one of Dr. A. O. C. Nier's mass spectrometers showed that the helium contained 0.1 percent air. The correction for this amounted to as much as 2 percent at some angles and energies, but was in general only a fraction of a percent.

The energy of the incident protons was corrected for losses in the Nylon entrance window to the chamber and for losses in the helium gas passed through before reaching the center of the scattering chamber.

Due to the finite size of the proton beam and the finite size of the solid angle subtended by the counter, "second-order geometry" corrections were made on the data similar to the corrections made on the proton-proton scattering data.[5]

RESULTS

The proton-helium differential cross sections in the center of mass system of coordinates are given in Table I and Fig. 2. The energies which are used as a parameter for the curves and which head the columns in the table are the incident proton energies in the laboratory system of coordinates. The errors given for the measured cross sections are the statistical errors which were calculated by using the reciprocal of the square root of the number of counts. The probable errors due to gas pressure measurements, charge measurement, measurement of geometrical factors, etc., amount to about 1.5 percent. When all errors are considered, the values of the cross section should be good to ± 3 percent. The 0.96-Mev data extend only to 99° as the scattered protons did not have enough energy to enter the counter at larger angles.

The differential cross-section curves have two interesting characteristics. First, as the energy increases, the curves depart markedly from the shape of Rutherford scattering curves down to

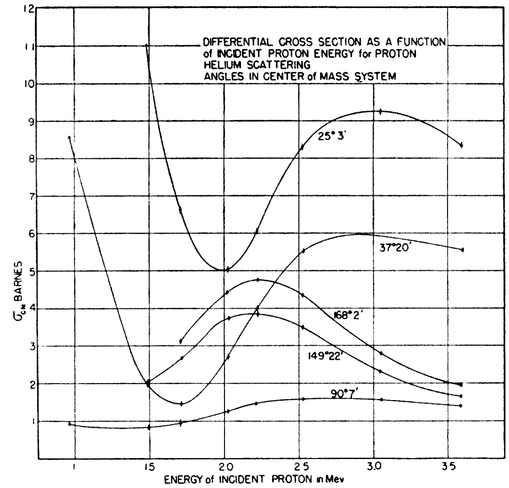

FIG. 3. Proton-helium scattering cross sections per unit solid angle in the center of mass coordinate system as a function of the energy of the incident protons in the laboratory system of coordinates. The angle parameter is the center of mass angle.

angles as low as 25°. Second, at large angles the differential cross section increases with energy, passes through a maximum at approximately 2.2 Mev, and then decreases.

To see the nature of this resonance, the values of the cross section have been replotted in Fig. 3 as a function of energy with angles serving as parameters. These curves show a broad resonance in the neighborhood of 2.2 Mev for backward scattering. However, the maximum of the resonance appears to shift to higher energies as the angle increases. These curves also show that the preferential backward scattering is done at the expense of scattering in the forward direction as the cross sections for small angles have a minimum at approximately the same energy as cross sections in the backward direction have a maximum. With the rather limited number of points on the energy scale there does not appear to be a double resonance in these curves. However, the nature of the resonance can only be established after a phase shift analysis of the data is completed. This analysis is now being done by Professor C. L. Critchfield and Mr. D. Dodder and will appear in a later publication.

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