The Elastic Scattering of Protons from Helium 4

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The absolute differential cross section has been measured for 31.6-Mev protons scattered elastically from helium. Seven increments of angles from 15° to 51° in the laboratory system of coordinates have been measured simultaneously, using proportional counters.

The observed nuclear scattering is approximately three times the calculated Rutherford scattering for a scattering angle of 17° in the center-of-mass system and approximately 100 times the calculated Rutherford scattering for an angle of 62° in the center-of-mass system. Also, the differential cross section for a center-of-mass angle 55° has been observed to be 59.1 millibarns/steradian for incident protons of 19.5 Mev in the laboratory system.

INTRODUCTION

THE elastic cross section for scattering of protons from He^4 has been measured at energies up to 9.5 Mev[1–5] and a phase shift analysis made for low energy protons.[6] The Berkeley proton linear accelerator has allowed the region of 32 Mev and below to be investigated. The apparatus which was used for proton-proton scattering[7] was used without modification to obtain data for elastic scattering of protons from helium 4 in the forward directions. An independent experiment giving the elastic and inelastic cross sections will also be reported in another paper.[8,9]

METHOD

The 31.6-Mev proton beam from the linear accelerator was deflected 12.6° in an analyzing magnet and a collimator 6 meters long gave a beam of 1-cm diameter, having a divergence of ±0.001 radian. The energy was calculated by measuring the deflection of the beam and the magnitude of the magnetic field along the trajectory. The beam entered the scattering chamber through a double 0.0002-in. Nylon foil and was scattered by helium at a pressure of slightly greater than one atmosphere. The scattered protons could be detected in either of nine proportional counters operated simultaneously. An additional counter detected only background neutrons and x-rays.

The fraction of the beam which was not scattered continued on through a 0.001-in. thick Duraluminum foil, and on into the Faraday cup, arranged as a charge integrator.

PROCEDURE

The scattering chamber was evacuated to a pressure of less than 10^{-5} mm of Hg and observed to be vacuum tight. Helium of greater than 99.5 percent purity (grade *A*), obtained from the Mathieson Company, was allowed to enter the scattering chamber through a

TABLE I. The differential cross section for the scattering of 31.6±0.3 Mev protons from helium 4. The tabulated counts are the actual counts divided by four and normalized to NTP and a collected charge of 306.9×10^{-12} coulomb. *T* and *B* refer to top and bottom halves of a given counter.

	Proton—He^4 scattering									Proton-proton scattering	
Mean angle (c.m.)	62.5°*T*	62.5°*B*	55.0°*T*	55.0°*B*	47.8°*T*	47.8°*B*	40.1°	24.8°	17.1°	102°–78°	90°–90°
Counts, run 1	352	337	474	469	···	657	1560	1554	1182	1.7	1.1
	365	350	512	474	···	668	1545	1490	1173	1.7	1.9
	386	314	509	479	···	618	1510	1520	1140	1.1	2.1
Counts, run 2	355	341	496	457	710	634	1498	1474	···	1.7	1.2
	350	385	447	480	666	658	1572	1530	···	1.9	1.2
	366	343	490	490	654	656	1546	1574	···	1.4	2.2
Total	2174	2070	2928	2849	2030	3891	9231	9142	3495	9.5	9.7
Total, both sectors		4244		5777		7851	9231	9142	6990	9.5	9.7
$(d\sigma/d\Omega)_{c.m.}$ mb/sterad		31.53		45.21		68.7	93.3	145.5	159.9	14.30	14.39
Prob. error		±0.8		±1.2		±1.8	±2.4	±3.8	±4.2	±0.15	±0.14
Calc. Rutherford cross section mb/sterad		0.315		0.503		0.847	1.65	10.75	47.1		

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liquid nitrogen trap made of stainless steel. The impurities before trapping were reported to be mostly hydrogen.

It was possible to measure the amount of hydrogen impurity by detecting the 90° coincidence scattered protons in the scattering chamber (see below).

The helium was admitted to the scattering chamber at a constant rate of approximately one liter per minute and allowed to bubble out through an oil lock column of Litton oil 5 cm high. The number of scattering nuclei was determined by measuring the height of this column, the barometric pressure, and the temperature of the has in the scattering chamber.

The position of the beam and the amount of multiple scattering of the beam were detected by inserting a photographic emulsion at the charge integrator. The beam was observed to have a mean diameter of 2.4 cm at the charge integrator. The charge integrator had an aperture of 6 cm; thus, the amount of the beam lost was negligible.

The scattered protons were detected by the same proportional counters which were used for proton-proton scattering.[7] The counter plateaus were determined by adjusting the gas multiplication and amplifier gain, making a run, then a background run with the shutter closed, and then repeating the run with a higher value of gas multiplication. The number of protons plus background was recorded for each of the ten counters. Also, the number of 90° coincidence counts was measured in the 45°–45° counters and in the 51°–39° counters. This was a measure of the hydrogen contamination in the helium, plus accidental coincidence.

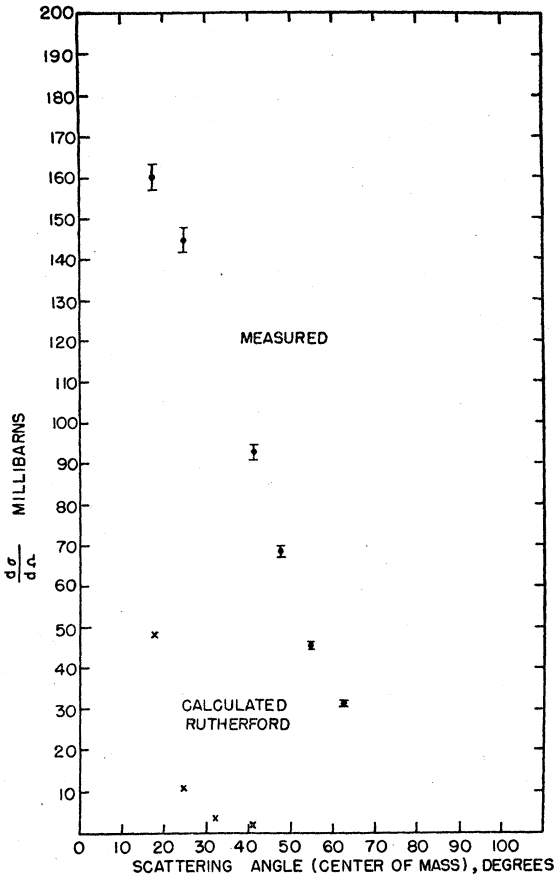

FIG. 1. Absolute cross section for elastic scattering of 31.6-Mev protons from He^4.

RESULTS

The data for two series of runs are given in Table I. The number of counts for each angle measured is tabulated, corrected for background, counter resolving time, and normalized to NTP. The counting rate was sufficiently low so that the correction for counter resolving time was always less than 1 percent. The "plateau" was such that for the first group of runs, a 50-volt increase in potential of the proportional counter wire indicated a 0.3 percent decrease in the scattering cross section, while in the second group of runs, a 1.1 percent increase in the scattering cross section was indicated. The statistical fluctuation was ±1.3 percent.

The number of 90° coincidence counts is tabulated for each of two sets of counters. The pulse repetition rate of the linear accelerator was 15 pulses per record, 400 microsecond long pulses. The resolving time of the coincidence circuit was 1.0 microseconds, and from the observed counting rate, the calculated number of accidental coincidence counts is 1.5 (unscaled) per run. From these corrected data and the measured cross section for proton-proton scattering,[10] the amount of hydrogen impurity is determined to be 1.0±0.5 percent. The corrections have been made for each angle assuming 1 percent hydrogen contamination and no other contamination. The calculated cross section for each angle is given in Table I. The assigned probable errors include the following:

a. Collected charge: ±½ percent.
b. Mean energy: ±1 percent.
c. Measurement of temperature and pressure: ±½ percent.
d. Slope of plateau: +1.5 percent.
e. Rms deviation of counts: ±1.5 percent.
f. Calculated geometry: ±¾ percent.
g. Contamination scattering: ±1 percent.

The rms value of these probable errors is ±2.6 percent.

Figure 1 is a comparison of the observed cross section with the calculated Rutherford cross section at this energy. A further comparison will be made in a following paper.[9]

Protons of 19.5-Mev incident energy were obtained by adjusting the radio frequency voltage distribution of the linear accelerator cavity.[10] The differential cross section was then measured at a center-of-mass angle of 55.0 degrees and observed to be 59.1±1.6 millibarns/steradian.

It is a pleasure to acknowledge the help of Professor Luis W. Alvarez, who made these experiments possible. Also, the continued patience of the linear accelerator crew, under the supervision of Robert Watt, has greatly simplified the process of obtaining data.

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