Elastic Scattering of 9.7-Mev Protons by He^4

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The differential cross section for the scattering of 9.7-Mev protons from helium has been measured over the range from 17° to 154° in the center-of-mass system. The new 9.9-Mev proton linear accelerator, which is now used as an injector for the Bevatron, was used as a source of incident protons. A scattering chamber has been used that has the solid angles at the various scattering angles determined by fixed slits. The scattered particles were detected with sodium iodide scintillators and RCA 6199 photomultiplier tubes.

The detectors were conveniently arranged so that each scintillator could be well shielded, and background runs could be made easily. The counters were arranged so that they could be interchanged and three angles have been measured simultaneously, with a statistical accuracy in the forward direction of better than ±1 percent. The differential cross-section measurements of the forward angles are in good agreement with published data in this energy region. However, the cross section for protons scattered in the backward direction is approximately 75 percent of the published value.

I. INTRODUCTION

THE elastic scattering of protons from helium has been measured at low energies,[1–6] and a phase-shift analysis has recently been made.[7,8] This is a many-body problem because of nuclear forces. However, to simplify the problem, it has been treated with the alpha particle regarded as acting as a tightly bound unit. On the basis of the previously published data, calculations by Breit[8] tend to favor a Gaussian type of potential well in preference to a long-tailed exponential well or a short-tailed square well. The 9.9-Mev proton linear accelerator,[9] which is now used as an injector for the Bevatron, has been used to measure both the differential proton-proton[10] cross section and the elastic proton-alpha cross section. The same scattering apparatus (see Fig. 3 of reference 10) was used for both experiments.

II. APPARATUS AND PROCEDURE

The scattering chamber has the solid angles at the various scattering angles determined by fixed rectangular slits. The scattered protons were detected with sodium iodide scintillators and RCA 6199 photomultiplier tubes. The detectors were conveniently arranged so that each scintillator could be well shielded, and background runs could be made easily. The counters were arranged so that they could be interchanged, and three angles were measured simultaneously.

The beam current was measured with a Faraday cup arranged with an automatic type of feedback integrator.[11]

Before a scattering experiment was started, the chamber was evacuated, flushed, and again evacuated to less than 10^{-5} mm mercury. Grade A helium, 99.95 percent pure, was admitted to the chamber through an activated charcoal trap which was cooled to liquid-nitrogen temperature. Most of the scattering experiments were done with a helium pressure of approximately 10 cm mercury.

The proton-beam energy was measured by determining the range in aluminum of the elastically scattered protons. A set of triple-coincidence proportional counters was used at the 30° angle, with the third counter connected in anticoincidence. The amount

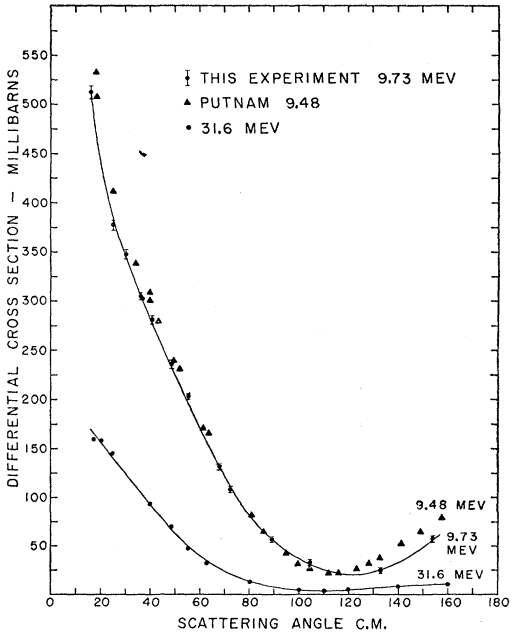

FIG. 1. Elastic scattering of 9.7-Mev protons by helium.

[1] Freier, Lampi, Sleator, and Williams, Phys. Rev. **75**, 1345 (1949).
[2] C. L. Critchfield and D. C. Dodder, Phys. Rev. **76**, 602 (1949).
[3] M. Heusikveld and G. Freier, Phys. Rev. **85**, 80 (1952).
[4] R. K. Adair, Phys. Rev. **86**, 155 (1952).
[5] Kreger, Kerman, and Jentschke, Phys. Rev. **86**, 593 (1952).
[6] T. M. Putman, Phys. Rev. **87**, 932 (1952).
[7] D. C. Dodder and J. L. Gammel, Phys. Rev. **88**, 520 (1952).
[8] Sack, Biedenharn, and Breit, Phys. Rev. **93**, 321 (1954).
[9] Bruce Cork, University of California Radiation Laboratory Report No. UCRL-2385, October, 1953 (unpublished).
[10] B. Cork and W. Hartsough, Phys. Rev. **94**, 1300 (1954).
[11] J. Benveniste and B. Cork, Phys. Rev. **89**, 422 (1953).

TABLE I. Elastic scattering of 9.73-Mev protons by helium.

$\theta_{c.m.}$	$d\sigma/d\Omega_{c.m.}$ (10^{-27} cm^2)
17°10′	512.6±7.2
25° 8′	374.9±4.5
30°56′	346.9±5.5
36°57′	305.0±3.6
37°16′	303.3±5.5
42°14′	281.2±3.1
49° 5′	236.9±3.1
55°40′	204.3±2.4
68°17′	132.5±1.6
72°27′	108.6±1.4
89°21′	57.0±1.6
104°23′	32.2±1.5
132°55′	24.5±0.7
154°15′	58.4±1.1

of aluminum absorber required to stop the scattered protons in the foil that separated the second and third counters was a measure of the proton energy. The incident proton beam was calculated to have an energy of 9.73±0.05 percent.

III. RESULTS

The uncertainties are estimated to be as follows: integrated charge, ±0.4 percent; solid-angle calculations, ±0.5 percent; pressure and temperature, ±0.3 percent; and proton energy, ±0.5 percent. Estimates were made of the loss in counts caused by multiple scattering in the helium; also, the pressure of the helium in the scattering chamber was changed over the range from 5 to 15 cm mercury and no corrections appear necessary. No corrections were made for scattering caused by contamination in the helium.

The differential cross section is plotted in Fig. 1 and tabulated in Table I. Some of the lower-energy data and the higher-energy data are shown on the same plot. It is observed that the measured cross section for 9.73-Mev protons scattered in the forward direction is lower but in good agreement with the 9.48-Mev data of Putnam. However, the cross section for protons scattered in the backward direction is approximately 75 percent of the value published by Putnam. Each of these deviations is in the direction which would be expected by extrapolation from lower and from higher energies,[12] but the deviation of the large-angle scattering is greater than the extrapolated value.

[12] Bruce Cork, Phys. Rev. 89, 78 (1953).

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Scattering of 9.5-Mev Protons by Nitrogen

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The elastic and inelastic scattering of 9.5-Mev protons by N^{14} nuclei has been studied by means of photographic emulsions. Groups of inelastically scattered protons have been observed due to the excited states of N^{14} at 2.3, 3.9, 4.9, and 5.1 Mev; the first of these was excited in a very low intensity. Angular distributions have been determined for the elastic group of protons as well as for the inelastic group corresponding to the 3.9-Mev state; the latter curve is symmetrical about 90°.

THE scattering of 9.5-Mev protons by various light elements has been studied with the beam of molecular hydrogen accelerated in the 60-in. Birmingham cyclotron; the scattering camera described by Burrows, Powell, and Rotblat[1] was used, after slight modification. Exposures were made with various gaseous targets; this note describes the preliminary results obtained with nitrogen.

The camera was filled with nitrogen at pressures of 19.9 cm and 14.8 cm. Ilford C2 emulsions, 200μ thick, were used to detect the scattered particles. The mean energy calculated from the ranges of elastically scattered protons was 9.45±0.01 Mev. Levels in N^{14} at 2.3, 3.9, 4.9, and 5.1 Mev have been observed as well as levels of higher excitation. The 2.3-Mev level was excited in surprisingly low intensity. Only after prolonged search over a large area of emulsion was it possible to detect the protons due to this level; we are able to set an upper limit of 7.0 millibarns for the total cross section for the inelastic scattering of protons from this state. The major contribution to this value comes from difficult measurements at forward angles, where the background of tracks due to elastically scattered protons penetrating the scattering gap wall is relatively high. At 45°, 65°, 115°, and 130°, where accurate measurements of the cross section were possible, we obtained values: 0.68±0.20, 0.26±0.08, 0.32±0.07,

[1] Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **A209**, 461 (1951).