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Berkeley, California

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May 24, 1954

## ABSTRACT

The differential cross section for the scattering of 9.7-Mev protons from helium has been measured over the range from $17^\circ$ to $154^\circ$ in the center-of-mass system. The new 9.8-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 $\pm 1\%$. 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% of the published value.

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## 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, Fig. 1, 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 have been 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% 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 anti-coincidence. The amount 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%.

### III. RESULTS

The uncertainties are estimated to be as follows: integrated charge, ±0.4%; solid-angle calculations, ±0.5%; pressure and temperature, ±0.3%; and proton energy, ±0.5%. Estimates were made of the loss in counts due to 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 due to contamination in the helium.

The differential cross section is plotted in Fig. 2 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% 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.

## Table I

Elastic Scattering of 9.73-Mev Protons by Helium

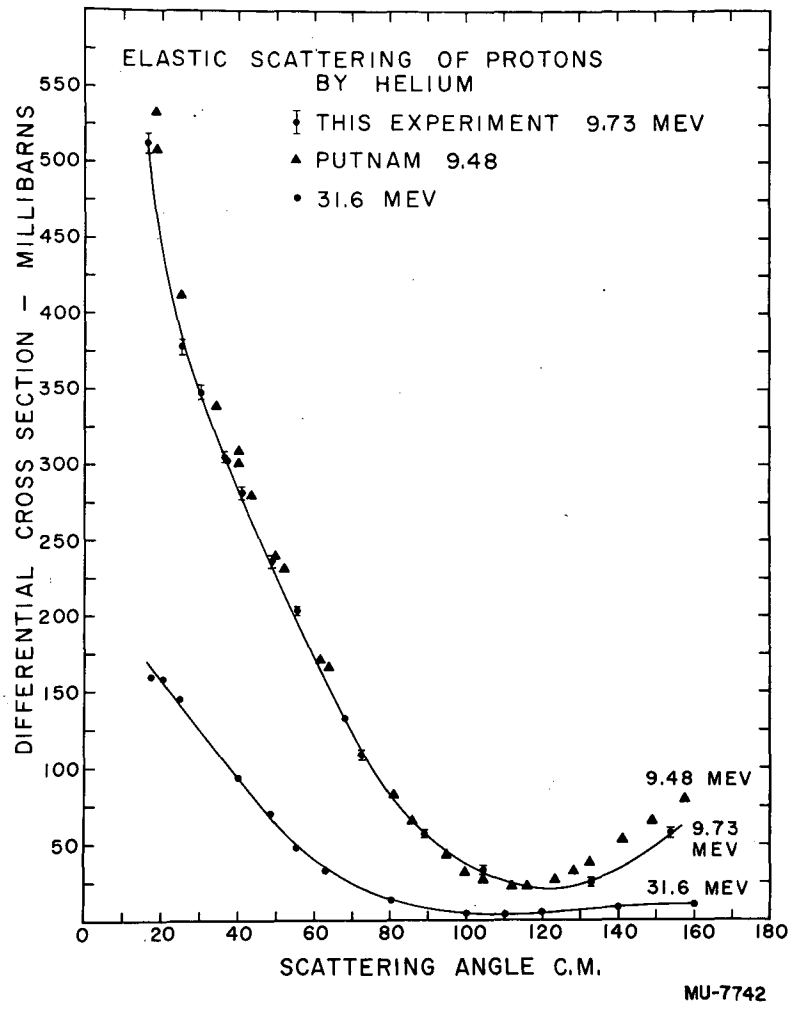| $\theta_{c.m.}$ | $\dfrac{d\sigma}{d\Omega}_{cm}$ $\times 10^{-27}$ cm$^2$ |
|---|---|
| 17° 10' | 512.6 ± 7.2 |
| 25° 8' | 374.9 ± 4.5 |
| 30° 56' | 346.9 ± 5.5 |
| 36° 57' | 305.0 ± 3.6 |
| 37° 16' | 303.3 ± 5.5 |
| 42° 14' | 281.2 ± 3.1 |
| 49° 5' | 236.9 ± 3.1 |
| 55° 40' | 204.3 ± 2.4 |
| 68° 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 |

Fig. 1

Fig. 2

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