Inelastic Scattering of Electrons from He^4†

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The inelastic scattering of electrons from He^4 which corresponds to a disintegration of the nucleus has been studied for incident electron energies of 400 and 500 Mev at laboratory angles from 45° to 135°. The energy spectra of the scattered electrons were measured, and absolute cross sections were found by comparison with elastic scattering from hydrogen. The curves were corrected for electron radiation. Within the validity of adapting to He^4 one of the results of the Goldberg theory of deuteron electrodisintegration, the cross sections at the maxima of the curves give a value of $M\langle 1/p\rangle_\alpha$ of (7.5 ± 1.5), where M is a nucleon mass and $\langle 1/p\rangle_\alpha$ is the expectation value of the reciprocal of the momentum of a nucleon bound in He^4. With a single exception, the energy-integrated cross sections $d\sigma_\alpha/d\Omega$ agree within experimental error with $d\sigma_\alpha/d\Omega=2(d\sigma_p/d\Omega+d\sigma_n/d\Omega)$, where $d\sigma_p/d\Omega$ is the free-proton cross section and $d\sigma_n/d\Omega$ is the neutron cross section found from inelastic scattering from deuterium.

I. INTRODUCTION

THE inelastic scattering of electrons from light nuclei which corresponds to a disintegration of the nucleus has been the subject of several recent investigations. Results have been given of experimental measurements of this process, in which only the recoil electrons were detected, for deuterium,[1–4] for Li^6 and Li^7,[5] and for Be^9 and C^{12}.[6] Preliminary measurements with He^4 have also been reported.[7]

For deuterium, this process has been interpreted as representing quasi-elastic scattering from the proton and the neutron which form the deutron. By subtracting the scattering due to the proton, which is taken from measurements of free-proton elastic cross sections, the scattering due to the neutron was found. Several theoretical studies[8–11] have been made which have given methods of making such an analysis. In the absence of a target of free neutrons from which to scatter electrons, these experiments have provided a measurement of the electromagnetic structure of the neutron.

For nuclei with Z greater than one, no theory of this interaction has been formulated in terms of proton and neutron cross sections, and the experimental results with these nuclei cannot provide any definite information about the neutron. A comparison of these results with those for the deuteron, however, serves as a measurement of the corrections necessary to a simple theory and may give some insight into the nature of the process. For He^4, a theory has been constructed[12] which contains parameters relating to the electromagnetic structure of He^4 and the residual nuclei He^3 and H^3.

It is the purpose of this paper to report on an experimental measurement of the inelastic scattering of electrons from He^4. Incident energies of 400 and 500 Mev were used, and absolute cross sections were found. They are interpreted by using some of the results of the theories of deuteron breakup that have been adapted to He^4.

II. THEORY

The experimental measurements of Yearian and Hofstadter[1–3] and Sobottka[4] on inelastic scattering from deuterium suggest two methods of interpreting the results of inelastic scattering from He^4. One method is simply to measure the area under the inelastic continuum to find the differential cross section $d\sigma_\alpha/d\Omega$. This cross section can be related to the proton elastic cross section $d\sigma_p/d\Omega$ and the neutron cross section $d\sigma_n/d\Omega$ by the following equation:

$$d\sigma_\alpha/d\Omega=2(d\sigma_p/d\Omega+d\sigma_n/d\Omega)(1+\Delta_\alpha). \quad (1)$$

The mathematical forms of the proton and neutron cross sections, which are based on work done originally by Rosenbluth,[13] have been given previously.[1] For $\Delta_\alpha=0$, this equation represents scattering from the nucleons in He^4 without interference. A discussion of the effects contained in this correction term and an estimate of its magnitude for the case of the deuteron have been given by Blankenbecler.[9] The method to be used with the He^4 data is to take $d\sigma_p/d\Omega$ in this equation from the measurements on the free proton[3] and $d\sigma_n/d\Omega$ from the deuteron results,[1–4] so that the experiment would serve as a measurement of the magnitude of Δ_α.

This is essentially the method that was used by

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[1] M. R. Yearian and R. Hofstadter, Phys. Rev. **110**, 552 (1958).
[2] M. R. Yearian and R. Hofstadter, Phys. Rev. **111**, 934 (1958).
[3] R. Hofstadter, F. Bumiller, and M. R. Yearian, Revs. Modern Phys. **30**, 482 (1958).
[4] S. Sobottka, Phys. Rev. **116**, 831 (1960).
[5] U. Meyer-Berkhout, Phys. Rev. **116**, 1300 (1959).
[6] H. F. Ehrenberg and R. Hofstadter, Phys. Rev. **110**, 544 (1958).
[7] R. Hofstadter, Revs. Modern Phys. **28**, 214 (1956).
[8] V. Z. Jankus, Phys. Rev. **102**, 1586 (1956).
[9] R. Blankenbecler, Phys. Rev. **111**, 1684 (1958).
[10] A. Goldberg, Phys. Rev. **112**, 618 (1958).
[11] L. Durand, Phys. Rev. **115**, 1020 (1959).
[12] T. Muto and T. Sebe, Progr. Theoret. Phys. (Kyoto) **18**, 621 (1957).
[13] M. N. Rosenbluth, Phys. Rev. **79**, 615 (1950).

Meyer-Berkhout[5] in interpreting the results of inelastic scattering from Li^6 and Li^7 and by Ehrenberg and Hofstadter[6] in interpreting those for Be^9 and C^{12}. Within experimental error, their results were found to be consistent with a zero value for the correction term. Some possible explanations of this were discussed by Meyer-Berkhout.[5]

The other method of interpreting the He^4 results involves simply a measurement of the cross section $d^2\sigma/d\Omega dE'$ at the peak of the continuum. This method was originally used in an attempt to reduce uncertainties resulting from the final-state interaction, which had been found to add counts to the high-energy sides of the curves,[8] and from the detection of electrons that have produced pions, which adds counts to the low-energy sides. This cross section can also be simply related to the proton and neutron cross sections by adapting to He^4 one of the results of the Goldberg impulse-approximation theory of deuteron electrodisintegration.[10] The equation to be used is the following:

$$\left(\frac{d^2\sigma}{d\Omega dE'}\right)_{\max}=M\left\langle\frac{1}{p}\right\rangle_\alpha \frac{1}{q}\frac{E}{E'}\left(\frac{d\sigma_p}{d\Omega}+\frac{d\sigma_n}{d\Omega}\right), \quad (2)$$

where E and E' are the initial and final energies of the scattered electron, q is the four-momentum transfer, M is a nucleon mass, and $\langle 1/p\rangle_\alpha$ is the expectation value of the reciprocal of the momentum of a nucleon bound in He^4. (The system of units with $\hbar=c=1$ is used.) The experiment would provide a measurement of the constant multiplicative factor $\langle 1/p\rangle_\alpha$. The procedure to be used is to fit the experimental angular distribution to angular distribution curves of this equation. It should be pointed out that the validity of this procedure is somewhat doubtful, since the approximations used in deriving this equation[10] should not hold as well for He^4 as for deuterium. If the results should agree with Eq. (1) for $\Delta_\alpha=0$, however, this might lend support to the validity of Eq. (2).

The He^4 results can also be compared to a theory of Muto and Sebe.[12] This theory includes two final states of the nuclear system, a proton plus H^3 and a neutron plus H^3, so that it contains parameters associated with these nuclei. Muto and Sebe pointed out that two types of transition matrix elements are involved: one representing a "direct" process, in which a nucleon is ejected through direct interaction with the electromagnetic field of the electron; and one representing an "indirect" process, in which a nucleon is ejected through a nuclear interaction with another nucleon which interacts with the electromagnetic field of the electron. One simple result[14] of this calculation is that if the "indirect" process is small, the energy of the peak of the continuum is given by

$$E_{\max}'=(E-\Delta M)[1+2(E/M)\sin^2(\theta/2)]^{-1}, \quad (3)$$

where ΔM is the mass difference between the alpha particle and a residual nucleus plus a nucleon.

Muto, Sebe, and Izumo[14] have already made comparisons between cross sections calculated from this theory and preliminary forms of some of the data of this experiment, using only the experimental shapes of the curves. Unfortunately, they used a form of the data that had not been corrected for radiative effects. This correction is discussed below; one of the effects it has is to modify the shapes of the curves, which means that the numerical results of this comparison may not be valid.

III. EXPERIMENTAL PROCEDURE

The analyzing and detecting apparatus was essentially the same as that used in the previous experiments.[1–6] Compressed helium gas, cooled with liquid nitrogen, was used as the target material. The pressure vessel has been described previously.[15] During data-taking, the target pressure was maintained at 2000 psi, and the temperature was monitored by means of thermocouples placed at each end of the target.

The target was placed in the momentum-analyzed beam of the Stanford Mark III linear accelerator. The scattered electrons were analyzed by the 36-in. spectrometer[7,16] and detected with a Čerenkov counter. Either a secondary emission monitor[17] or a large Faraday cup was used to supply a signal to the beam integrator, which was a vibrating reed electrometer with an external capacitor.

Inelastic continua were measured at 400 and 500 Mev at angles between 45° and 135°. Absolute cross sections were found for each continuum by comparison with a hydrogen elastic scattering curve measured at the same angle with the same incident electron energy. This peak was always measured on the same run as the He^4 continuum. Hydrogen gas contained in the same pressure vessel was used as the target material. Because of the low counting rates, the statistical accuracy attained was not very great. The points at the peaks of the He^4 continua generally contained about 100 counts and those at the peaks of the hydrogen curves 150 to 250 counts.

To minimize error resulting from a background of negative pions being detected in the counter, two precautions were taken. First, the pulse-height discriminator was set at a fairly high level. (The same setting was used for both the He^4 continuum and its comparison proton peak.) Then, for each continuum, the direction

[14] T. Muto, T. Sebe, and K. Izumo, Progr. Theoret. Phys. (Kyoto) **22**, 304 (1959).

[15] G. R. Burleson and H. W. Kendall, Nuclear Phys. **19**, 68 (1960).

[16] E. E. Chambers and R. Hofstadter, Phys. Rev. **103**, 1454 (1956).

[17] G. W. Tautfest and H. R. Fechter, Rev. Sci. Instr. **26**, 229 (1955).

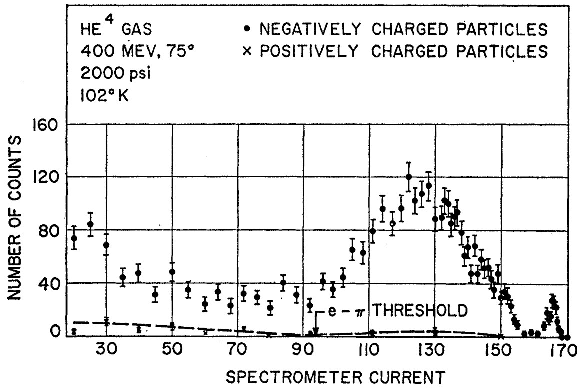

FIG. 1. Experimental data found for scattering from He^4 at 400 Mev, 75°.

of spectrometer current was reversed, and the spectrum of positively charged particles was measured. This pion contamination could then be corrected for by making a subtraction of this spectrum from the continuum.

With the small-angle continua, an elastic scattering peak also appeared in the electron spectrum. Absolute cross sections for these were found by a comparison with the hydrogen peak. The statistical accuracy of some of these peaks was not very good, however, since they were not of primary interest.

The raw He^4 data found at 400 Mev, 75°, are shown in Fig. 1. The elastic scattering peak appears at the high-energy end of the spectrum (larger values of spectrometer current), and the increase in the number of counts on the low-energy side is due to an overlap with the peak representing pion production. Counts of positively charged particles are also shown. The proton peak found at 400 Mev, 90°, which is fairly typical, is shown in Fig. 2.

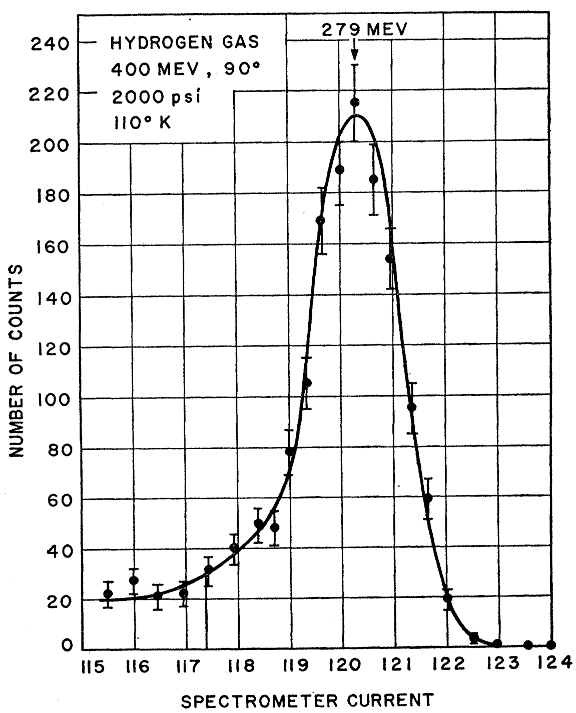

FIG. 2. The hydrogen elastic scattering curve found at 400 Mev, 90°.

IV. DATA ANALYSIS

The following corrections were applied to each He^4 inelastic spectrum to reduce it to the form of the differential cross section $d^2\sigma/d\Omega dE'$ as a function of the recoil energy E':

(a) A correction for the loss of counts resulting from the detecting apparatus not being able to accept more than one count per machine pulse (60 pulses per second) was applied. This was necessary for the small-angle data only, and it was never greater than three or four percent.

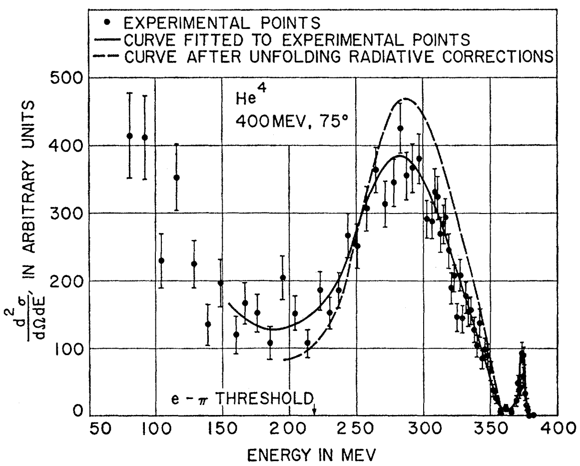

FIG. 3. The corrected inelastic curve found at 400 Mev, 75°.

(b) The background of π^- mesons was corrected for by subtracting the spectrum of positively charged particles from the continuum. The error introduced in these results by the uncertainty in the measurements of the π^-/π^+ photoproduction ratio in[18] He^4 is less than two percent; this ratio was found to be of order unity.

(c) If a He^4 elastic peak was found, its low-energy tail was extrapolated into the continuum and subtracted from it.

(d) The scale of potentiometer current, the abscissa of the spectrum in Fig. 1, was converted to an energy scale.

(e) The spectrometer dispersion correction was applied. This compensates for the width of the vertical exit slits of the spectrometer remaining constant, which corresponds to a constant momentum resolution, and it amounts to multiplying each point by a factor of $1/E'$.

[18] M. J. Jakobson, A. G. Schulz and R. S. White, Phys. Rev. **91**, 695 (1953).

The continuum of Fig. 1 as corrected in this manner is shown in Fig. 3 by the curve drawn with a solid line.

Finally, a correction for electron radiation before, during, and after the scattering process was applied to the data. A discussion of the nature of this process and a derivation of a form the correction can take is given by Sobottka.[4] A numerical procedure equivalent to solving Eq. (A5) of reference 4 was constructed,[19] and with the aid of an electronic computer this correction was applied to each continuum. The continuum of Fig. 1 so corrected is shown in Fig. 3 by a dashed line. Its behavior with respect to the curve uncorrected for radiative effects is typical. The ratio of the corrected peak height to the uncorrected height is greater than unity and decreases fairly uniformly for increasing angle; its value at 400 Mev, 45°, is 1.33 and at 400 Mev, 135°, is 1.15.

Corrections equivalent to these were also applied to the hydrogen and helium elastic peaks.

The relative densities of helium and hydrogen gas

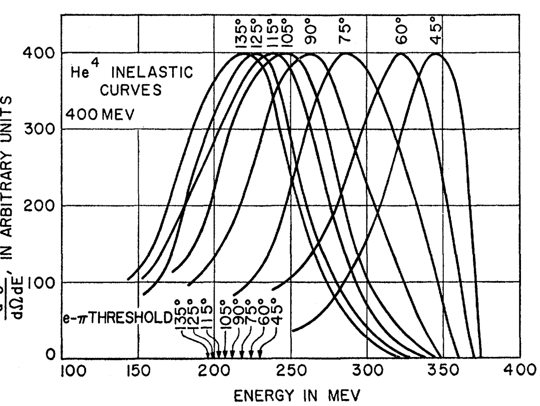

FIG. 4. The corrected inelastic curves found at 400 Mev.

at 2000 psi at the temperatures used were taken into account in calculating absolute cross sections. These densities were calculated as described in reference 15.

In order to find the differential inelastic cross section $d\sigma_\alpha/d\Omega$, integrals of the continua were taken over the recoil electron energy E'. This amounted to measuring the areas under the curves. This measurement is difficult, since the low-energy tails of the continua partly overlap with the high-energy tails of the pion production peak. There is at present no theory which gives an expression for the shape of the pion-production peak which is accurate enough to use to make a subtraction, and there is no experimental means of distinguishing the two processes if the recoil electron only is detected. Therefore, to measure the areas, the thresholds for this process were calculated and the tail of each curve was drawn, using what was judged to be a reasonable extra-

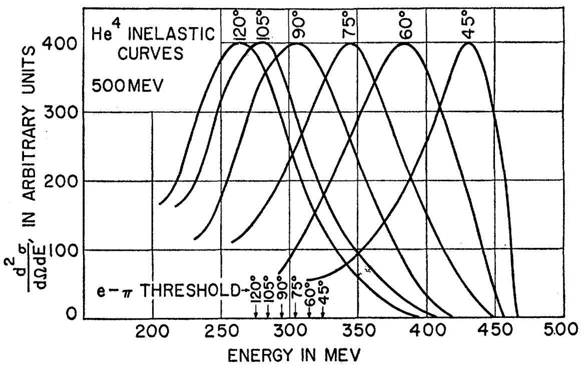

FIG. 5. The corrected inelastic curves found at 500 Mev.

polation. The error introduced by this procedure was estimated by drawing in other tails to give limits and measuring the difference in the areas.

V. RESULTS AND DISCUSSION

The experimental He[4] curves, with all corrections applied, are shown in Figs. 4 and 5. The vertical scales of the curves have been adjusted to give the same height, and the thresholds of the pion peaks are indicated. The extrapolated tails are not shown, and no experimental points are shown, but for most of the curves the statistical accuracy is about the same as in Fig. 3. The peaks of the curves lie between 10 and 18 Mev below the free-proton peaks, and in general the agreement with Eq. (3) is good, except for small angles, where the peaks are found at a slightly higher energy. The width of the 400 Mev, 45°, curve is about 60 Mev; of the 400 Mev, 60°, and 500 Mev, 45°, curves about 70 Mev; and of the other curves (90±10) Mev.

A previous measurement[20] of the curve at 400 Mev, 60°, indicated the possibility of some form of structure on the high-energy side. This structure was reproduced by Muto and Sebe[12] in numerical fit of their theoretical expression to the curve, in which it was attributed to the contribution from the "indirect" process. In the experimental measurements of this curve, particular attention

TABLE I. Experimental inelastic peak cross sections found at 400 Mev. The errors shown are the statistical standard deviations.

Angle	$d^2\sigma/d\Omega dE'$ at peak (cm²/sr-Mev)
45°	$(1.80\pm0.13)\times10^{-32}$
45°	$(1.87\pm0.10)\times10^{-32}$
60°	$(5.82\pm0.58)\times10^{-33}$
60°	$(5.88\pm0.48)\times10^{-33}$
75°	$(1.93\pm0.19)\times10^{-33}$
90°	$(1.11\pm0.11)\times10^{-33}$
105°	$(6.05\pm0.58)\times10^{-34}$
115°	$(4.22\pm0.39)\times10^{-34}$
125°	$(3.77\pm0.33)\times10^{-34}$
135°	$(2.87\pm0.25)\times10^{-34}$

[19] An account of the procedure used is given in a thesis submitted to Stanford University in partial fulfillment of the requirements for the Ph.D. degree in Physics.

[20] See Fig. 13 of reference 7.

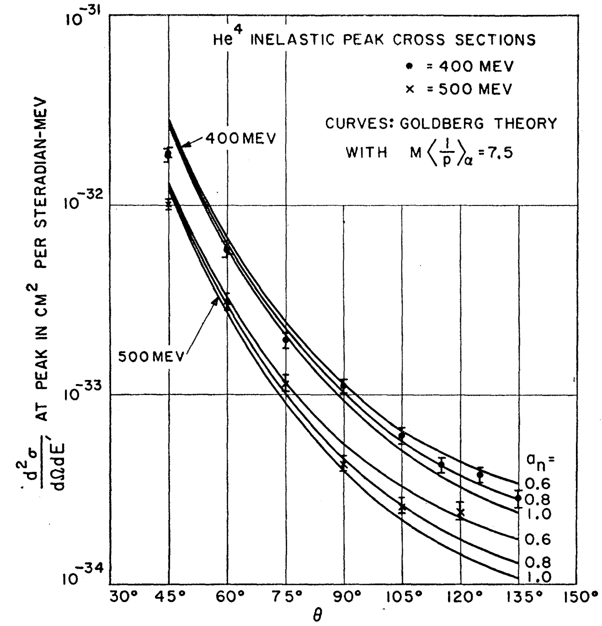

FIG. 6. Experimental inelastic peak cross sections. The errors shown are the statistical standard deviations. The curves are predictions of the Goldberg theory, as adapted for He^4, for values of a_n for the neutron of 0.6, 0.8, and 1.0 f and for a value of $M\langle 1/p\rangle_\alpha$ of 7.5.

was paid to the high-energy side, but no definite evidence of structure was found. Moreover, no structure was observed in any of the other continua. It is possible, however, that some form of structure would be found if greater statistical accuracy and an improved energy resolution could be used.

The absolute cross sections at the maxima of these continua are shown in Fig. 6, together with curves of Eq. (2) for neutron cross sections corresponding to values of a_n of 0.6, 0.8, and 1.0 f, where a_n is the size parameter in the neutron magnetic moment form factor for an exponential model,[3,7] which has the form

$$F_n(q)=(1+q^2a_n^2/12)^{-2}. \quad (4)$$

[The measurements of Yearian and Hofstadter[1–3] found a value of a_n of (0.80 ± 0.15) f.] The quantity $M\langle 1/p\rangle_\alpha$ in this equation has been set equal to 7.5. This value was chosen simply by sliding the family of curves of $[(1/q)(E/E')(d\sigma_p/d\Omega+d\sigma_n/d\Omega)]$ until a fit was found.

TABLE II. Experimental inelastic peak cross sections found at 500 Mev. The errors shown are the statistical standard deviations.

Angle	$d^2\sigma/d\Omega dE'$ at peak (cm^2/sr-Mev)
45°	$(1.03\pm0.05)\times10^{-32}$
60°	$(3.10\pm0.29)\times10^{-33}$
75°	$(1.17\pm0.11)\times10^{-33}$
90°	$(4.36\pm0.43)\times10^{-34}$
105°	$(2.61\pm0.24)\times10^{-34}$
120°	$(2.47\pm0.25)\times10^{-34}$

It was judged that this method gave a value of $M\langle 1/p\rangle_\alpha$ of (7.5 ± 1.5), taking all errors into account. The errors shown are the statistical standard deviations only. The numerical values of these cross sections are given in Tables I and II. It should be pointed out that the angular distributions of curves given by Eq. (2) do not differ greatly from those given by curves of $(d\sigma_p/d\Omega+d\sigma_n/d\Omega)$ alone, and the experimental points for the cross sections at the maxima of the continua fit either equally well. The fit with the angular distribution of $d\sigma_p/d\Omega$ is, however, rather poor.

The cross sections $d\sigma_\alpha/d\Omega$ are shown in Fig. 7, together with curves of $2(d\sigma_p/d\Omega+d\sigma_n/d\Omega)$ for values of a_n of 0.6, 0.8, and 1.0 f. The errors shown include both the statistical standard deviations and the errors intro-

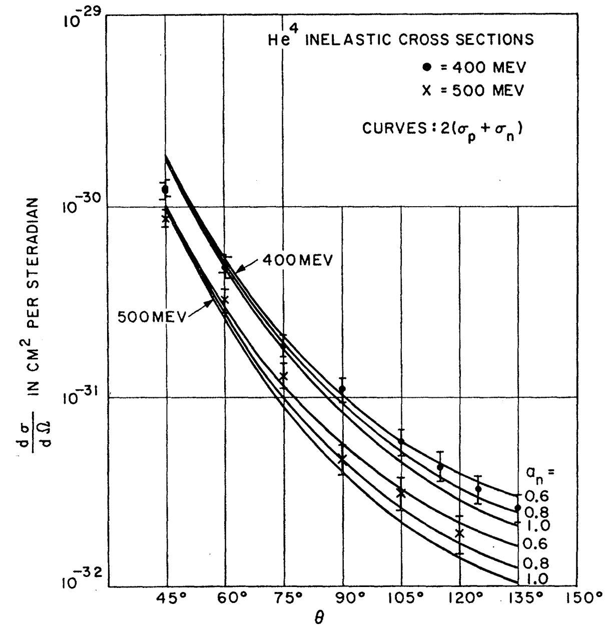

FIG. 7. Experimental inelastic cross sections. The errors shown represent uncertainties due to counting statistics and to the measurement of the areas of the curves below the pion-production threshold. The curves shown are $2(d\sigma_p/d\Omega+d\sigma_n/d\Omega)$ for values of a_n for the neutron of 0.6, 0.8, and 1.0 f.

duced by the extrapolation of the low-energy tail. The extrapolation error varied from 6% at 400 Mev, 45°, to 20% at 500 Mev, 120°, where the overlap with the pion-production peak was greatest. The numerical values of these cross sections are given in Tables III and IV.

The cross sections for the two curves at 400 Mev, 45°, are surprisingly low. The peak cross sections for these curves also seem to be low with respect to the other points, as is seen in Fig. 6. One possible explanation of this is the mixing of nucleon ejections with deuteron ejection, which, according to Muto, Sebe, and Izumo,[14] tends to increase in the forward direction. To give an idea of the amount of mixing necessary to account for the reduced cross section, the following equation may be used:

$$d\sigma_\alpha/d\Omega = (1-\delta)(2d\sigma_p/d\Omega + 2d\sigma_n/d\Omega) + \delta(2d\sigma_d^e/d\Omega), \quad (5)$$

where $d\sigma_d^e/d\Omega$ is the deuteron elastic scattering cross section. Using the measurement of McIntyre and Burleson[21] for the deuteron elastic scattering cross section at 400 Mev, 45°, the value of δ necessary to satisfy this equation is 0.4. Further theoretical and experimental investigation, including more small-angle measurements, would be necessary to establish this result.

The rest of the points in Fig. 7 are consistent, within error, with Eq. (1), with $\Delta\alpha = 0$. For a nucleus in which the nucleons are so tightly bound, this may seem fairly surprising, but it is consistent with the results for Li^6, Li^7, Be^9, and C^{12}, as well as with those for deuterium. It is possible, of course, that more careful measurements might reveal discrepancies among these various results. Because of the theoretical and experimental uncertainties involved in this analysis, a value of a_n extracted from these data is not very significant, but it can be noted that the experimental points in Fig. 7 tend to favor one slightly smaller than 0.8 f.

TABLE III. Experimental inelastic cross sections found at 400 Mev. The errors shown represent uncertainties due to statistics and to the measurement of the area of the curve below the pion-production threshold.

Angle	$d\sigma/d\Omega$ (cm^2/sr)
45°	$(1.22\pm0.12)\times10^{-30}$
45°	$(1.13\pm0.09)\times10^{-30}$
60°	$(4.75\pm0.62)\times10^{-31}$
60°	$(5.00\pm0.55)\times10^{-31}$
75°	$(1.86\pm0.24)\times10^{-31}$
90°	$(1.09\pm0.15)\times10^{-31}$
105°	$(5.69\pm0.85)\times10^{-32}$
115°	$(4.12\pm0.62)\times10^{-32}$
125°	$(3.25\pm0.52)\times10^{-32}$
135°	$(2.58\pm0.44)\times10^{-32}$

The He^4 elastic scattering cross sections are shown in Fig. 8. They are plotted in the form of $(d\sigma/d\Omega)/(d\sigma_M/d\Omega)$ as a function of q, where $d\sigma_M/d\Omega$ is the Mott cross section.[15] In the absence of anomalous electron interactions,[15] this quantity equals the nuclear form factor $F(q)$ for He^4. A previous measurement of this quantity,[15] more accurate than the present one, which was made with a multichannel detector, found $F(q)$ to correspond to the Fourier transform of a Gaussian charge distribution with an rms radius of (1.68 ± 0.04) f. The points found in the previous measurement, together with the curve of this form factor for an rms radius of 1.68 f, are also shown in Fig. 8. The agreement between the two sets of data is satisfactory, and it serves as a check of the consistency of the two experimental methods.

[21] J. A. McIntyre and G. R. Burleson, Phys. Rev. **112**, 2077 (1958).

TABLE IV. Experimental inelastic cross sections found at 500 Mev. The errors shown represent uncertainties due to statistics and to the measurement of the area of the curve below the pion-production threshold.

Angle	$d\sigma/d\Omega$ (cm^2/sr)
45°	$(8.65\pm0.78)\times10^{-31}$
60°	$(3.21\pm0.45)\times10^{-31}$
75°	$(1.30\pm0.20)\times10^{-31}$
90°	$(4.61\pm0.83)\times10^{-32}$
105°	$(3.11\pm0.59)\times10^{-32}$
120°	$(1.91\pm0.44)\times10^{-32}$

There are several other sources of error in these results. The error in the radiative corrections to the inelastic continua is estimated to be two to three percent at the peaks and four to six percent in the tails. Errors due to an uncertainty in the density of the gas in the target, to small fluctuations in the spectrometer current, and in the incident beam energy are estimated to be the order of two or three percent. The uncertainty in the absolute value of the proton cross section, which is about eight percent at the largest energies and angles,[22] introduces error into the absolute value of the He^4 cross sections. This error does not affect the interpretation of the results as given in Figs. 6 and 7, however, since a change in the proton cross sections would affect the theoretical curves and the experimental points in these figures equally.

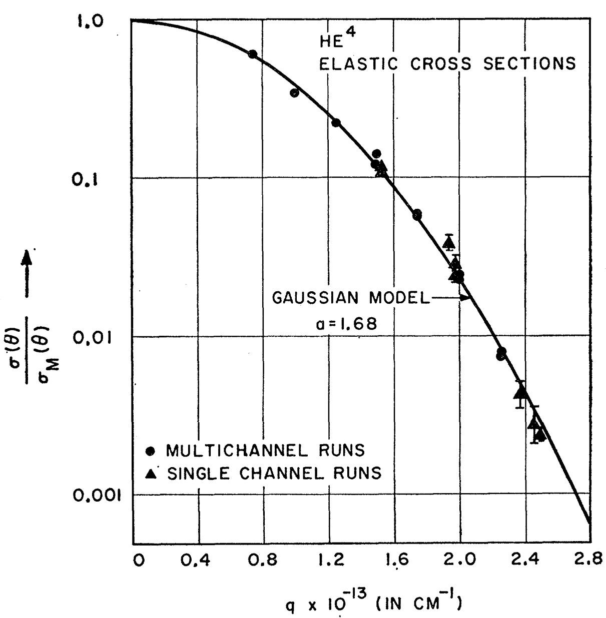

FIG. 8. Experimental values of $(d\sigma/d\Omega)/(d\sigma_M/d\Omega)$ plotted as a function of the four-momentum transfer q. The errors shown are the statistical standard deviations. Also shown are data found in an earlier measurement with a multichannel detector.

[22] F. Bumiller (private communication).

Because of the low counting rates, fairly large spectrometer entrance slits were used. This probably resulted in a variation in the transmission of the spectrometer with electron recoil energy. Such a variation would affect the energy-integrated cross sections $d\sigma_\alpha/d\Omega$ but not the peak cross sections, since the recoil energies of the electrons in the normalizing proton peaks were the same as those of the maxima of the continua. The error introduced by this effect in the tails of the continua is estimated to be the order of the statistical error in the experimental points defining the tails.

The additional uncertainty in these results due to the other sources of error is estimated to be about five percent in the peak cross sections and 10 or 12% in the energy-integrated cross sections.

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Photodisintegration of the Deuteron from 500 to 900 Mev*

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The reaction $\gamma+d\rightarrow p+n$ has been studied for photon energies between 500 and 900 Mev. Bremsstrahlung from the California Institute of Technology electron synchrotron was incident on a liquid deuterium target. Measurements of the energy and angle of the protons arising in the interactions were sufficient to establish that photodisintegration without pion emission occurred and also to determine the energy of the photon which gave rise to the detected proton. An excitation curve was obtained at 90° in the laboratory and angular distributions were measured for photon energies of 500 and 700 Mev. The total cross section decreased smoothly from 7 μb at 500 Mev to 1 μb at 900 Mev.

I. INTRODUCTION

THE photodisintegration of the deuteron has been studied extensively from 2.23 Mev to 455 Mev.[1–4] Up to energies of about 10 Mev these experiments provided a complement to low-energy n-p scattering and radiative capture experiments.[1] Between 10 and 200 Mev[2–4] the increasing role played by mesons is observed in a region where such particles exist only in virtual states. Above meson threshold[2–4] photodisintegration experiments are useful as checks on the internal consistency of meson theories.[5] The present experiment extends the cross-section measurements to 900 Mev. An excitation curve was measured at 90° in the laboratory and angular distributions were obtained for photon energies of 500 and 700 Mev. The results show that the total cross section decreases smoothly from 7.0 $\pm1.0\,\mu$b at 508 Mev to $1.0\pm1.0\,\mu$b at 913 Mev.

II. EXPERIMENTAL PROCEDURE

General Considerations

The experiment was performed by measuring the energy and angle of protons arising from the reaction

$$\gamma+d\rightarrow p+n. \quad (1)$$

Photons of the bremsstrahlung beam produced by the Caltech electron synchrotron were incident on a liquid deuterium target. Figure 1 is a plan view of the experimental arrangement and Fig. 2 shows details of the telescope.

The angle and energy of the proton determine the kinematics of reaction (1). Since protons arise from reactions other than (1), it is necessary to insure that the observed protons did not come from other processes

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