Angular Distribution of 10.8 Mev Deuterons Scattered by Deuterons*

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Cross sections for the elastic scattering of deuterons by deuterons have been measured for incident energy of 10.8 Mev at laboratory angles from 17.5 degrees to 57 degrees at 2.5 degree intervals. The deuteron beam from the Los Alamos cyclotron was focused on a thin gas target containing deuterium, and the scattered deuterons were detected in a proportional counter. A selsyn-controlled foil shutter mounted in front of the counter prevented He^3, and H^3 at angles greater than 40 degrees, from entering the counter. H^1, and H^3 at the smaller angles, were discriminated against by using a ten-channel pulse amplitude analyzer. Typical values of the elastic scattering cross section at 10.8 Mev, in barns per unit solid angle, are given in the table for several angles in the center of mass system. The experimental curve is symmetrical about 90 degrees in the center of mass system.

θ	35°	40°	50°	60°	70°	80°	90°
σ	0.283	0.235	0.158	0.127	0.109	0.099	0.094

I. D–D SCATTERING

While the deuteron-deuteron scattering interaction is much more complicated than a two-particle interaction, few enough nucleons are involved to make data pertaining to this reaction of value to the development of a nuclear force theory. This is made especially true by the recent advances in modern computing methods.

The differential d-d scattering cross section is fairly well known for bombarding energies below 3.5 Mev,[1,2] and relative values have been obtained at 7 Mev.[3] The results of the measurements given here have been given in an abstract at the Seattle Meeting of the American Physical Society.[4]

II. EXPERIMENT AND RESULTS

The present scattering study was carried out with the 10 Mev deuteron beam from the Los Alamos cyclotron focused into a reaction chamber about 15 feet away from the cyclotron. A proportional counter, mounted so as to rotate to any angle in the horizontal plane, detected the particles produced in a thin gas target mounted in the center of the reaction chamber. The general instrumentation has been discussed in a previous report.[5] For this experiment, however, the gas target has been redesigned so that it is $7\frac{1}{2}$ inches long with a $\frac{9}{16}$-inch$\times 3\frac{1}{2}$-inch Nylon window in each side of the target, through which reaction particles were counted from 17.5 degrees to 57.5 degrees to the direction of the beam in the laboratory system. Besides having the beam collimated to ± 0.6 degree by slits and anti-scattering diaphragms as it enters the $\frac{3}{16}$-inch diameter 2.5-mil Nylon entrance window of the gas target, there was included inside the target $1\frac{11}{32}$ inches behind this Nylon window an anti-scattering diaphragm to remove the deuterons scattered by the front window. A more detailed discussion of this target is soon to be published.[6] On the support of the proportional counter[5] there was mounted a vertical slit adjustable to either $\frac{1}{16}$-inch or $\frac{1}{8}$-inch width to define the beam of scattered deuterons which are detected by the counter. The reaction volume was defined by this slit and the $\frac{1}{8}$-inch diameter hole immediately in front of the proportional counter. Anti-scattering diaphragms between the slits and counter aperture removed deuterons scattered from the slit support. The beam current was measured with a Faraday cage. The accuracy of this measurement has been previously checked.[7] Immediately in front of the proportional counter was mounted a selsyn controlled foil shutter with which 100 combinations of absorbers could be selected.

Before and after the experiment, the position of the beam relative to the counter window was determined by scanning the beam with the counter used as an ionization chamber. The position of the beam had remained constant to 0.1 degree.

The procedure for taking the data was essentially the same as that described in a previous report.[7] For scattered deuterons the absorber foils in front of the counter were adjusted with consideration for the range of triton groups which are produced by the $D(d,p)H^3$ reaction. At angles beyond 40 degrees, the triton group was generally excluded by the absorber foils; near 20 degrees, however, where the range of tritons approaches the range of scattered deuterons, the foils were adjusted so that the tritons' range ended just beyond the counter. The pressure of the counter was such that the air equivalent of the path of particles in the counter was about 10 cm. The amplified pulses from the counter

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were analyzed by means of a ten channel amplitude discriminator. Figure 1 gives a sample deuteron peak obtained. The abscissa gives the amplified pulse height. The ordinate gives the number of pulses per two-volt interval having the magnitude given as the abscissa. Since the tritons were near the end of their range when they entered the counter, the energy lost by them in the counter is higher than that due to the scattered deuterons. Therefore, the peak from the triton group lies above that of the deuteron group. From the known thickness of absorbers in front of the counter, and from the range energy curve of deuterons and tritons, one calculates the expected position of the triton peak relative to the deuteron peak. For almost all of the curves obtained the calculated position and the observed position agreed well. In a few cases, however, where the triton group ended part of the way through the counter, uncertainties in the thickness of absorbers used caused large variations in the ionization due to the triton peak. In such cases where the triton peak was not resolved, the triton pulses were counted in with the deuteron peaks and the resulting data was later corrected for the triton contribution, by use of the measured $D(d,p)H^3$ cross section.

The curve indicated by the crosses was obtained by adjusting the absorbers to stop the deuterons before they entered the counter. This gives the counter background. Since the absorbers were adjusted by remote control while the cyclotron beam was held constant, and since the background run was taken immediately after the peak run, the shift in background due to changing beam conditions was minimized. For the conditions used in this experiment, the background under the peak was, on the average, 8.3 percent of the peak counts. A number of checks were tried to test the validity of the background corrections. For pairs of runs at certain angles, the pressure of deuterium gas in the target was changed by as much as a factor of two. Although the background relative to peak varied by a factor of two, the cross section obtained from the data was the same to within the reproducibility of the measurements (the order of 2.5 percent). In another

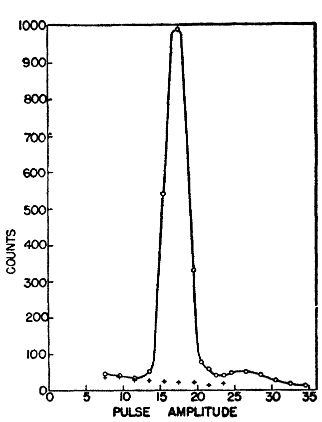

FIG. 1. Distribution of pulses from proportional counter due to deuterons scattered at 32.5 degrees. The crosses represent the background obtained by stopping the deuterons before they reach the counter.

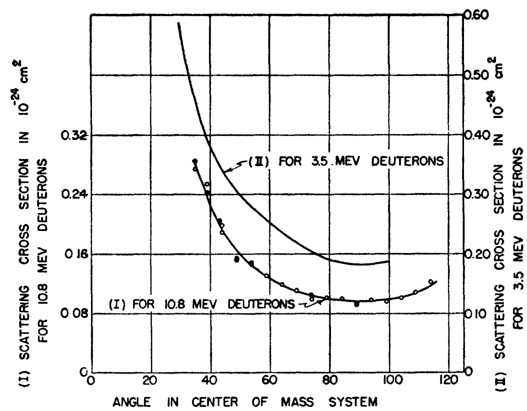

FIG. 2. Differential cross section for deuteron scattering in the center of mass system.

test, runs were made at certain angles in which the thickness of absorber in the path of the scattered deuterons was decreased from 27-cm air equivalent to 17-cm air equivalent. Under these conditions the number of counts in the peak remained constant to about two percent.

Immediately after each run, the energy of the deuteron beam was determined by magnetic deflection.[5] During the course of the experiment the beam energy varied by ± 2.8 percent, but all the data was corrected to the average energy. For this correction, the rate of change of cross section with energy was estimated from interpolation between data from low energy[2] and the present data. Since the maximum correction for energy was only 2.5 percent, this procedure introduced a negligible error.

Figure 2 is a plot of the differential cross section in the center of mass system as a function of center of mass angle. The root mean square deviation of the points from the smooth curve is ± 2.5 percent. This is about the spread expected from the consideration of the statistical error, the variation of the beam position, the random error in current determination, and uncertainty in measuring the background. Systematic errors, such as errors in aligning the slits, measuring distances, and absolute current measurements, amount to 2.5 percent. Combining this error with the random error of the points, we estimate the curve in Fig. 2 is good to ± 3.5 percent.

The curve through the points is accurately symmetrical about 90 degrees, which is a further check of consistency of the data. The points designated by solid circles were obtained by opening the first defining slit for the scattered deuterons from $\frac{1}{16}$-inch to $\frac{1}{8}$-inch wide. The fact that the points so obtained lie on the smooth curve through the previous points is a check on the reliability of the slit measurements. The latter points also indicate that a decrease of the angular resolution of the counter system by 33 percent has no observable effect on the data even in the steep region of the curve.

III. CONCLUSIONS

The preliminary results from photographic plate detection at 40 degrees, 60 degrees, and 80 degrees using a 10 Mev beam[8] agree with the 10.8 Mev data within the limits of error. Over the angular region of the measurements the scattering is almost entirely nuclear. Calculated coulomb scattering at 35 degrees amounts to 4.7 percent of the total differential scattering cross section for 10.8 Mev. For comparison the d–d scattering at 3.5 Mev is included in Fig. 2.[2] The differential cross section is somewhat lower for the higher energy data; at 90 degrees the ratio of the cross section at 10.8 Mev to that at 3.5 Mev is 0.523. For 10.8 Mev scattering the cross section remains more nearly constant over a wider angular region near 90 degrees than for 3.5 Mev scattering.

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On the Production of Π-Mesons by Nucleon-Nucleon Collisions

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Besides the doubts concerning the actual meson theories, and the use of a perturbation method for the study of strongly coupled fields, doubts have been raised as to the validity of some approximations usually made in the computation of the cross section for meson production by nucleon-nucleon collision. This cross section is computed here in a relativistically invariant manner for the pseudoscalar meson (pseudoscalar coupling) with the charged and the charge symmetrical theory. The results are valid for all energies of the incoming particle. The energy distribution and the total cross section derived from the invariant statistical factors are given as a point of comparison. Some computational tools are presented: a projection and a permutation operator and a method for the calculation of the density of states. In the Appendix two different ways of considering the meson production (mesonic analog to the bremsstrahlung or third-order process) are discussed.

THE problem of the production of mesons has interest for the origin of mesons in cosmic rays and for the artificial production of mesons. Many papers have been published on the production of mesons by collision between nucleons.[1–9] In the actual state of the theory, there exists no satisfactory method to compute the cross sections for the production of mesons:

(1) The equation of propagation of the meson field and the form of the interaction between the nucleon field and the meson field are not known.

(2) The perturbation method is not adapted to the study of strongly coupled fields. Attempts to circumvent the inadequacy of the perturbation method for problems involving mesons have not yielded entirely reliable methods. In the absence of an invariant relativistic method which gives the solution to radiative scattering problems without making an expansion in terms of powers of the coupling constant, the study of the multiplicity of the mesons produced in each collision is not really possible.

Besides these basic difficulties, illegitimate approximations have often been made in the course of the calculations. Taking advantage of the new computational techniques, the cross section for the production of a meson is computed here in a relativistically invariant manner. Hence, the result shares the large uncertainty of the present meson theories and of the use of the perturbation method, but it is not impaired by undue and unnecessary approximations.

We compute here the cross section for the production of a pseudoscalar meson with pseudoscalar coupling

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