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RESEARCH PROGRESS MEETING

February 19, 1948

R. K. Wakerling

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RESEARCH PROGRESS MEETING

February 19, 1948

R. K. Wakerling

Deuteron-Proton Scattering. By K. Bruekner Much of the cloud chamber work has been directed toward obtaining the angular distribution of protons bombarded by deuterons from the 184-inch cyclotron. The observations have been restricted to those protons arising from neutrons of energy greater than 65 Mev. The cloud chamber used for this work is of 16-inch diameter and employs a magnetic field of 14000 gauss. The chamber is filled with hydrogen at a pressure of $1/2$ atmosphere; the vapor used is water and alcohol.

Nearly 800 proton tracks were measured and calculated before analysis of the data indicated that the measuring procedure should be revised. They gave the angular and energy distributions shown in Figures 1 and 2. The discrepancies between the theoretical and experimental energy distribution of the neutrons shows that serious errors were being made. As a first check of possible sources of error, random parts of the data were remeasured. They indicated that errors in the measurements of the angles were being made that gave a mean deviation of about $\pm 2^\circ$ in the beam angle and $\pm 4^\circ$ in the dip angle. These errors were largest at large scatter angles. In addition, a more serious error occurred in the measurements of the curvature. The mean deviation was as large as 15 percent, with many tracks having errors of 50 to 100 percent in the measured curvature. These errors were due to the fact that an adequate measuring technique had not been developed, that the original measuring apparatus and projector

FIGURE 1

ENERGY DISTRIBUTION OF NEUTRONS
FROM THE 190 MEV DEUTERON BEAM
AS CALCULATED FROM CURVATURE
OF THEIR KNOCK-ON PROTONS

LEGEND:

— CLOUD CHAMBER DATA CALCULATED
FROM 762 KNOCK-ON PROTONS

--- THEORETICAL DISTRIBUTION
OF NEUTRONS PRODUCING
KNOCK-ON PROTONS

38 NEUTRONS HAD MEASURED
ENERGIES > 190 MEV

NUMBER OF TRACKS
(ANNULUS)

ENERGY IN MEV

FIGURE 2

-4-

were difficult to operate, and that the cloud chamber technique had not been perfected. A systematic analysis of the errors and difficulties involved in the experiment made it evident that revisions in the technique were necessary.

In view of the inaccuracy of the original measurements it is not possible to make more than a qualitative analysis of the first 800 tracks. The data showed definitely the existence of exchange forces and point to the conclusion that classical forces are slightly dominate in the proton-neutron reaction at these energies. This is indicated by the excess of high angle scattering, with 246 protons scattered at angles greater than 45° and 183 scattered at angles less than 45° . It is to be noted that this excess existed despite a selective tendency for the increased errors at large scatter angles to exclude the data from the group having energy greater than 65 Mev.

The data taken under revised and improved procedure shows good agreement with theoretical energy distribution as may be seen from Figure 3. The angular distribution given in Table I now shows more definately the asymmetry of the scattering, with 59 protons scattered at angles greater than 45° and 38 at angles less than 45° . However, the probable statistical errors are still relatively large, and there is still a possibility that errors are introduced from high energy protons knocked on in the forward direction which may not ionize heavily enough to be observed. This effect is small since the protons now being observed are knocked on in hydrogen at one and one half atmospheres pressure with the resulting much greater ionization.

E. Segre. The angular distribution of n-p scattering with 90 Mev

FIGURE 3

TABLE I

Number per annulus in laboratory system

Lab angle	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89
	3	8	10	12	12	16.8	23.4	11.9	3.6

Distribution per equal cosine interval in
the center of mass system

C.M. Angle	0-52	53-78	79-100	101-126	127-180
	19	14	13	23.7	27.7

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neutrons has been measured in the center of mass system between the angles of 70° and 170° . Figure 4 shows the schematic layout of the apparatus. The neutron beam produced by stripping 180 Mev neutrons in a beryllium target was collimated to a diameter of about 2.5 centimeters and scattered by paraffin or polyethylene targets which were larger in diameter than the neutron beam. The recoil protons used for the measurement were detected by a set of three proportional counters in coincidence and placed in a line pointing towards the scatterer. The primary neutron beam was monitored either by the protons scattered by an auxiliary hydrogenous target or by a bismuth fission chamber. The set of three coincidence counters was made insensitive to protons with an energy below a certain minimum by means of an absorber of aluminum placed between the second and third counters. The thickness of absorber was so adjusted that the protons of energy less than $66 \cos^2 \frac{\pi - \theta}{2}$ Mev could not enter the third counter.

Table II gives the cross section as a function of angle. The data are also plotted in Figure 5 with the relativity correction. Smaller and larger angles are being investigated at the present time.

These experiments were performed independently with two separate sets of equipment which were similar in principal but different in many details. This procedure helped considerably in revealing unsuspected causes of trouble. A very careful study was made of the sources of systematic error and it is felt that these preliminary results may be viewed with some confidence.

TABLE II

DIFFERENTIAL CROSS SECTION IN 10^{-28} cm^2
(normalization hypothetical)

The errors listed are based only on statistical standard deviations.

Scattering Angle θ	(1)	(2)	(3)	(4)
70	43.7 ± 4.0	35.3 ± 2.9	39.0 ± 3.7	40.8 ± 3.1
80	42.6 ± 3.5	32.5 ± 4.9	40.4 ± 3.7	40.2 ± 2.5
90	42.0 ± 2.4	44.0 ± 4.2	45.1 ± 4.9	43.5 ± 2.4
100	47.0 ± 3.0	42.4 ± 6.1	48.0 ± 3.7	46.7 ± 2.7
110	50.2 ± 3.4	51.8 ± 6.1	53.0 ± 3.5	51.4 ± 2.5
120	59.0 ± 2.7	59.7 ± 6.3	63.2 ± 4.5	60.4 ± 2.4
130	66.8 ± 3.1	70.0 ± 7.0	61.5 ± 3.8	65.6 ± 2.7
140	79.5 ± 3.1	78.5 ± 7.8	84.7 ± 5.6	81.2 ± 2.8
150	92.5 ± 4.4	99.0 ± 7.0	94.0 ± 5.4	94.1 ± 4.1
160	105.5 ± 3.8	127.0 ± 10.6	107.5 ± 7.9	107.7 ± 3.8
170	126.0 ± 5.8	127.5 ± 14.0	123.2 ± 9.4	125.7 ± 5.0

θ Neutron scattering angle in the center of mass system.

(1) Composite of runs on apparatus 1.

(2) Run on apparatus 2, scatterer $150 \text{ mg/cm}^2 (\text{CH}_2)_n$

(3) Run on apparatus 2, scatterer $283 \text{ mg/cm}^2 (\text{CH}_2)_n$

(4) Weighted average of all runs with estimated error.

PLAN VIEW OF EXPERIMENTAL ARRANGEMENT

FIG. 4

DIFFERENTIAL CROSS SECTION IN 10^{-28} CM^2

80° 100° 120° 140° 160° 180°
TERING ANGLE
FIG. 5

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The peak of protons in the forward direction is a clear indication of the existence of the exchange forces between neutron and proton. A more detailed analysis that takes into account the total scattering cross section and the angular distribution indicates that there might be comparable amounts of ordinary forces.

R. Serber. Calculations are being made to account for the scattering results found. To start with, the potential

$$V = C \frac{e}{r} - r/1.2 \times 10^{-13}$$

has been used, which had previously been found to work at low energy. In these calculations one half exchange and one half ordinary force was assumed. On this basis variations of scatterings with angle of the type shown in Fig. 6 (curve 1) was discovered. A total cross

Figure 6

section of .087b was thus found which compares favorably with McMillan's measured value of $.083 \pm .004b$. However, if the tensor forces are introduced into the calculation the curve number 2 is obtained, which gives totally different result. This means of course that the potential is not correct. Unfortunately if the

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range is increased the cross section found to increase. Relativistic corrections should also be made but these are difficult.

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