The Scattering of 2.6 Mev Neutrons by Heavy Hydrogen Nuclei

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Our understanding of the structure of light nuclei is awaiting further experimental knowledge of the interactions between the nuclear constituents. From recent experimental work[1] on the scattering of neutrons of mean energy 2.6 million electron-volts energy in ordinary hydrogen in a Wilson chamber, conclusions have been drawn regarding the radius and strength of interaction of the neutron with the proton. The experiments show a spherically symmetrical distribution of proton recoils with scattering angle in the center of mass reference system. The neutrons producing the recoils are those of mean energy 2.6 Mev from the deuteron-deuteron reaction. The distribution of proton recoils observed was according to the cosine of the angle of scattering measured. The description of such scattering, the S-scattering, is that only those neutrons have a large probability of being scattered which have no orbital angular momentum about an axis through the protons encountered, i. e., executive head-on collisions.

The interaction between neutron and proton has been successfully described by a pair of potential wells of different depths and widths for the triplet and singlet states in the deuteron. From the S-scattering observed, no test is provided for specific assumptions regarding the character of the n-p force, as to whether it involves an exchange of charge, of spin, or of both, or no exchange at all.

The present experiment on the scattering of neutrons by deuterons was undertaken in the hope that it would provide a check on the symmetry of the forces, in the neutrons and protons, i. e., on whether the neutron-neutron force is the same as the proton-proton force, excepting the Coulomb repulsion of the protons. This would be determined by comparing the distribution of deuteron recoils in the present experiment with the distribution resulting from the scattering of protons by deuterons, provided that the protons were of the same energy, about 2.6 Mev. Another point of interest in the neutron-deuteron scattering is whether it is possible to represent the interaction by a suitable fixed potential hole, or if the deuteron is "polarized" by the incident neutron, so that higher orders of approximation to the nuclear three-body problem are necessary.

The angular distribution of 328 tracks of recoil deuterons has been studied. These tracks have been selected from one thousand tracks measured on 3,000 photographs, which were taken with the aid of an expansion chamber. The chamber was filled with 54.3 per cent deuterium, 37 per cent argon, 6 per cent nitrogen, and 2.7 per cent heavy water vapor; this mixture was bombarded with neutrons of 2.6 Mev energy from the deuteron-deuteron reaction: deuterons plus deuterons give helium three plus neutron plus disintegration energy, Q.

The criterion for selecting the above-mentioned 328 tracks was established by using: (1) the calculated stopping power of the gas mixture, (2) the pressure variation within which tracks can form, (3) the energy-range relationship for deuterons,[2] and (4) the energy variation in the neutrons caused by (a) loss of energy of the incident deuteron beam in the thick heavy-ice target and (b) the angular aperture of the detector. To these selected tracks have been applied the necessary azimuthal, area, and random track corrections, in a manner similar to that used in the study of the scattering of neutrons by protons.[3]

The observed distribution of deuterons, in the laboratory reference system, expressed as per cent number of tracks per unit of solid angle found in each 10° scattering angle interval, is the following: 25 per cent in (0°-9°), 16 per cent in (10°-19°), 12 per cent in (20°-29°), 8 per cent in (30°-39°), 9 per cent in (40°-49°), 12 per cent in (50°-59°), 13 per cent in (60°-69°), 5 per cent in (70°-79°).

Although these results are based on a small number of tracks (328), the data indicate that there is present a marked deviation from spherically symmetrical scattering in the center of mass system. More data are needed to establish the reality of the peak in the curve at scattering angle 60°. Plotted in the center of mass system against the scattering angle in that system, the data seem to follow the curve expected if P-scattering is included, i.e. approximately a quadratic expression in the scattering angle. Such a variation has been found by Massey and Mohr,[4] assuming rectangular potential holes of radii 4×10^{-13} cm and 6×10^{-13} cm, except that the variation of our curve is a much more rapid falling off at small angles, and perhaps a deviation at large angles. The minima of observed and calculated curves coincide with respect to the abscissa. It seems plausible that the choice of a different potential hole, with further regard for the structure of H^3 might allow better agreement with this experiment. The deviation at large angles, if real, would require higher orders of partial waves in the description of the scattered neutron. The deviation at small angles may require for its explanation a potential depending on the polarization of the deuteron by the incident neutron. The polarization potential, superimposed on the fixed potentials assumed for the n-p and n-n interactions, would be slowly varying, acting over longer distances than the ordinary potential. Its effect would be to introduce many spherical harmonics into the description of the scattered neutron wave, which would interfere strongly at the large scattering angles, but would pile up the intensity at the small angles.

An important side result of this investigation is the calculation of the energy of disintegration, Q, of the deuteron-deuteron reaction. The range of a recoil deuteron at 0° scattering angle has been found by "extrapolating" the curves of numbers of tracks against track length along the steepest tangents to the length axis, for the intervals 0°-10°, 0°-20°, 0°-30°. These ranges were reduced to ranges in air under standard conditions through multiplication by the calculated stopping power of the mixture with respect to air. Proper corrections[5] were made for obtaining the mean range, and the range-energy relation for deuterons[6] gave the energy of the deuteron. Considerations of momentum and energy conservation make the disintegration energy Q equal to 3/2 of the energy of the recoil minus ⅓ of the energy of the deuteron beam incident on the target. For the three intervals mentioned, the calculated Q's were 3.39, 3.38, and 3.38 Mev, ± 0.09 Mev, in good agreement with the result of Bonner,[7] 3.29 ± 0.08 Mev.

FOOTNOTES

1 The Scattering of Neutrons by Protons, P. Gerald Kruger, W. E. Shoupp, and F. W. Stallmann, Phys. Rev. *52*, 678, 1937.
2 H. Bethe, Physical Review, *53*, 313, 1938.
3 Cf. Reference 1.
4 H. W. S. Massey and C. B. O. Mohr, Roy. Soc. Proc., *148A*, 206, 1935.
5 M. S. Livingston and H. A. Bethe, Reviews of Mod. Physics, July, 1937.
6 Cf. Reference 2.
7 T. W. Bonner, Phys. Rev., *53*, 711, 1938.