LETTERS TO THE EDITORS

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Collisions of Neutrons with Deuterons and the Nature of Nuclear Forces

ATTEMPTS to decide the nature of the forces between elementary nuclear particles by investigation of the distribution in angle of protons projected by neutrons have so far proved fruitless. This is because the only source of neutrons, homogeneous in velocity, at present available is the D - D reaction, which yields neutrons of 2.2 mv. energy. The wave-length of these neutrons is so long compared with the range of the neutron - proton forces that only those particles which make head-on collisions are effective in the scattering. These particles give an isotropic distribution of the scattered intensity in relative co-ordinates independent of the nature of the neutron - proton force.

To obtain information more sensitive to the nature of the forces it is necessary to investigate collisions of neutrons with simple nuclear structures of dimensions comparable with the wave-length of 2.2 mv. neutrons. We have therefore carried out a detailed theoretical investigation of the collisions of neutrons with the simplest of such structures, namely, deuterons.

The interaction energy between any two nuclear particles, ij , was taken to be of the form

$$- [mM + hH + \{ \frac{1}{2}(1-x) - h \} B + \frac{1}{2}(1+x) - m] A e^{-\alpha ij},$$

where M , H , B are the Majorana, Heisenberg and Bartlett exchange operators. x is the ratio of the force between particles of opposite spin to that between particles with the same spin and has the known value 0.6. The constants A and α were taken to be those given by Present and Rarita¹ as the ones which lead to binding energies of H^2 , He^3 , He^4 in best agreement with that observed. Three distinct sets of values of m and h were taken for detailed calculation:

- (1) Mixed exchange force.
 $m = \frac{1}{2}(1 + 3x)$, $h = \frac{1}{2}(1 - 3x)$.
- (2) Majorana-Heisenberg exchange force.
 $m = \frac{1}{2}(1 + x)$, $h = \frac{1}{2}(1 - x)$.
- (3) Ordinary force.
 $m = 0$, $h = 0$.

The method employed in calculating the scattering follows that of resonating group structure introduced by Wheeler². Exchange of particles is taken into account but the polarization of the deuteron by the incident neutron is neglected. The integro-differential equations involved were solved by numerical methods.

In Fig. 1 the calculated angular distribution, in relative co-ordinates, for the scattering of 1.85 mv. neutrons by deuterons is illustrated for each of the assumed types of force (1), (2) and (3). It will be seen that curve 3, corresponding to ordinary forces (case (3)), shows a much more marked variation of scattering with angle than either of the other

CALCULATED ANGULAR DISTRIBUTION (IN RELATIVE CO-ORDINATES) OF NEUTRONS OF 1.85 MV. ENERGY SCATTERED BY DEUTERONS.

Curve 1, assuming 'mixed' exchange forces.

„ 2, „ Majorana-Heisenberg exchange forces.

„ 3, „ 'ordinary' forces.

two. The recent experiments of Barschall and Kanner³ indicate that there is little variation in scattered intensity in the angular range of their observations (70-135°). This suggests that the fundamental nuclear forces are really of exchange type approximating to (1) or (2).

The evidence from the total collision area Q also points the same way. The measurements of Aoki⁴ give $Q = 2.2 \times 10^{-24}$ cm.² for D-D neutrons. We find for cases (1), (2) and (3) respectively 2.25, 1.79 and 3.37×10^{-24} cm.², strongly favouring (1).

It thus appears that very useful evidence regarding nuclear forces can be obtained by a detailed study of neutron - deuteron collisions. It is hoped that further experimental evidence will be forthcoming.

A detailed account of the theory will be published in the *Proceedings of the Royal Society*. It would not have proved possible to complete the numerical solution of the equations involved but for a grant from the Government Grants Committee of the Royal Society, which enabled us to employ the professional services of the Scientific Computing Service.

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¹ *Phys. Rev.*, **51**, 788 (1937).

² *Phys. Rev.*, **52**, 1083 (1937).

³ *Phys. Rev.*, **53**, 590 (1940).

⁴ *Proc. Phys.-Math. Soc. Japan*, **21**, 232 (1939).