Scattering of Neutrons by Protons

THEORETICAL investigations of the interaction of protons and neutrons have been given by Wigner, Heisenberg and Majorana. A very valuable check on their conclusions is provided by the study of the scattering cross-section of the hydrogen nucleus for neutrons of various energies. Cross-sections have been measured for neutrons of low energies (a few volts) by Fermi and his collaborators[1]; for the photo-neutrons from heavy hydrogen (energy about 250 k.v.) by Goldhaber[2]; and for the neutrons obtained by bombarding carbon with heavy hydrogen (600–1,200 k.v.) by Tuve and Hafstad[3]. Dunning[4] also gives a value for the fast portion of the continuous spectrum of radon-beryllium neutrons, of which the average effective scattering energy probably lies in the region of 3–4 m.e.v.

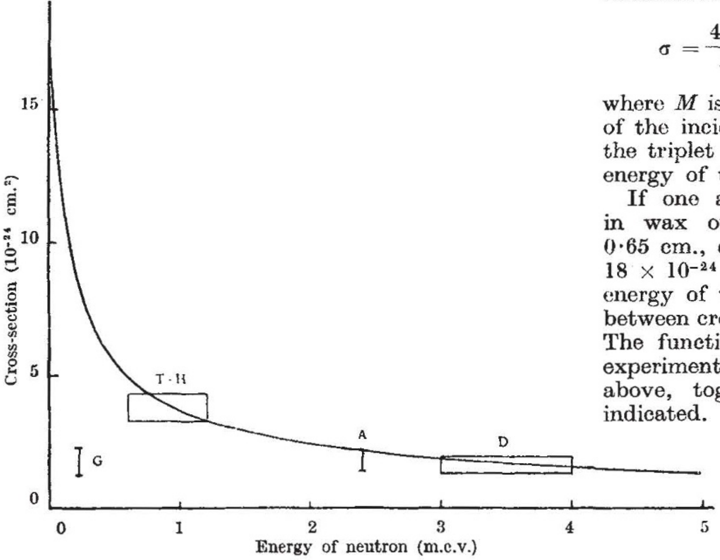

FIG. 1. The curve represents Wigner's theoretical neutron-proton scattering cross-section for neutrons of various energies. Experimental results of various investigators are also shown: G = Goldhaber; T-H = Tuve and Hafstad; A = Booth and Hurst; D = Dunning.

We have measured the cross-section of protons for the 2·4 m.e.v.[5] neutrons obtained from the D + D reaction. A fast neutron detector, consisting of an indium foil embedded in a block of paraffin wax 9·5 cm. × 5·5 cm. × 6·5 cm. was placed 23 cm. from the heavy phosphoric acid target. This detector was wrapped in cadmium foil to prevent so far as possible the entrance of any slow neutrons reflected from the surrounding walls: extraneous neutrons would tend to make the measured value of the cross-section too low. The scatterer consisted of a sheet of paraffin wax 7·7 cm. long, 4·8 cm. wide and 1·85 cm. thick. This was placed midway between the target and the detector. A thin packet of phosphorus, which responds only to fast neutrons, was placed near the target to enable a correction to be made for small variations in the intensity of the neutron source. The activities induced in the phosphorus and indium were measured on a Geiger-Müller counter.

Ten runs, five with and five without the scatterer, were made. After correcting for neutrons which were scattered and yet entered the detector, a free path of 4·6 ± 0·9 cm. was obtained for the neutrons in the wax. For the carbon correction, we adopted Dunning's value of $1 \cdot 7 \times 10^{-24}$ cm.^{2} for the scattering cross-section, for fast neutrons in carbon. After applying this correction we find a cross-section of $(1 \cdot 8 \pm 0 \cdot 4) \times 10^{-24}$ cm.^{2} for 2·4 m.e.v. neutrons scattered by protons.

A theoretical formula, assuming singlet and triplet states for the neutron-proton system, has been derived by Wigner. This gives the cross-section as a function of energy in the form

$$\sigma = \frac{4\pi\hbar^2}{M}\left[\frac{1}{4}\cdot\frac{1}{\varepsilon^1 + \frac{1}{2}E_0} + \frac{3}{4}\cdot\frac{1}{\varepsilon + \frac{1}{2}E_0}\right],$$

where M is the mass of the proton, E_0 is the energy of the incident neutron, ε is the binding energy of the triplet state (2·15 m.e.v.) and ε^1 is the binding energy of the singlet state.

If one adopts Fermi's value for the free path in wax of the DABI neutron groups, namely, 0·65 cm., corresponding to a cross-section of about 18×10^{-24} cm.^{2}, one can determine the binding energy of the singlet state and obtain the relation between cross-section and energy of incident neutron. The function is shown graphically (Fig. 1). The experimental results of the investigators mentioned above, together with our own value, are also indicated. The agreement between theory and experiment is satisfactory at the higher energies, but further experimental work seems to be needed in the intermediate region between 0·1 and 1 m.e.v.

A target of heavy ice cooled with liquid air has been installed since the above experiment was completed. As a consequence the neutron yield has been increased by a factor of five, and we hope to repeat the measurements using phosphorus as the neutron detector.

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[2] Goldhaber, NATURE, **137**, 824 (1936).
[3] Tuve and Hafstad, *Phys. Rev.*, **50**, 490 (1936).
[4] Dunning, *Phys. Rev.*, **45**, 586 (1934).
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Inconsistency of the Neutrino Theory of Light

The neutrino theory of light proposed by Jordan[1] postulates a connexion between the quantized wave function of the light field (F) and that of the neutrino field (Ψ). Since Ψ satisfies the commutation rules for Fermi statistics and F those of the Bose statistics, the connexion cannot be a linear one. On the other hand, we know from quantum electrodynamics that F satisfies a linear differential equation; a similar equation of d'Alembert's type is to be expected for Ψ. Thus a contradiction arises between the linearity of the equations and the non-linearity of the connexion between F and Ψ. (This contradiction is avoided only in the case of plane waves propagating in one definite direction.) Besides, serious doubts arise as to the possibility of expressing the quantized amplitudes $b(\nu)$ for F (Bose statistics) in terms of the amplitudes $\gamma(\nu)$ for Ψ (Fermi statistics), the operators $b(\nu)$ and $\gamma(\nu)$ being of a quite different mathematical nature.