THE ELASTIC SCATTERING OF NEUTRONS IN DEUTERIUM

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Introduction

The experimental study of the elastic scattering of elementary particles by light atomic nuclei is of great theoretical interest, since it reveals the nature of short range fundamental nuclear forces pertaining to the atomic nucleus. A good bit of experimental work on the scattering of neutrons by protons and of protons by protons has been carried out already and some interesting theoretical conclusions deduced therefrom. The available experimental data in regard to the scattering of neutrons by deuterons are, however, meagre. The value of scattering cross-section of $5.7 \times 10^{-24}$ cms. found in the experiments of Carroll and Dunning are 20% too low compared with the theoretical value computed by Motz and Schwinger and the discrepancy is attributed to possible polarisation effects. The results in regard to neutron-deuteron scattering obtained by Barschall and Kanner lead Massey and Buckingham to conclude that the fundamental forces may be of the exchange type and to stress the urgent need of a more extensive set of experimental data to arrive at more definite theoretical conclusions.

Experimental

An experimental study of the scattering of medium fast neutrons of 0.3 to 1.5 Mev. energy in deuterium gas conducted by the present authors is presented in this paper. The neutrons were produced by the nuclear reaction represented by the equation

$$^{4}\text{Be}^9 + ^1\text{H}^2 \rightarrow ^6\text{Li}^1 + ^5\text{B}^{10}$$

using deuterium ions accelerated by the cascade-built one-million volt transformer at the high voltage laboratory of the California Institute of Technology. The accelerating tube was of the short ion path type and was operated at 600 kilo-volts peak voltage with an ion current of 4 micro-amperes. The neutron spectrum produced at this voltage in the Be-D nuclear reaction has
been found\(^9\) to give rise to nearly equal intense groups of 4·1, 3·6, 2·3 and 1·2 Mev. energy neutrons. The neutron beam proceeding from the solid beryllium target in a direction perpendicular to the stream of bombarding deuterons traversed a brass pressure ionisation chamber filled with deuterium gas at a pressure of 100 lbs. wt. inch.\(^{-2}\). The energy of recoil deuterons in the ionisation chamber which was of 10 cms. diameter and 1 cm. depth was measured by a Dunning type\(^6\) linear amplifier. The amplifier fed a mechanical oscillograph and the pulses were recorded on a moving photographic film. The calibration was carried out by registering on the same film, both at the start and finish of a run of the accelerating tube, pulses corresponding to a known charge of the order of 10\(^{-14}\) coulombs on the collecting electrode of the chamber, with a thyratron pulse generator and a standard condenser. Fig. 1 gives

![Diagram](image)

**Fig. 1**

a sketch of the arrangement employed to obtain calibration pulses. The pulses registered in the recording arrangement were visually checked by a three-inch screen cathode ray oscillograph. The longest pulse track on the film corresponded to an energy of about 2 Mev. and the total number of tracks measured on several lengths of film was in the neighbourhood of 4000. In Fig. 2 is given a reproduction of a portion of a film registering the energy of the recoil deuterons. A graph giving the total number of deuterons of different energies of recoil is shown in Fig. 3. The distribution-in-energy curve shows two peaks—one at 0·7 Mev. and a less pronounced one at about 1·3 Mev. energy.
Discussion

It is to be expected that the recoil deuterons in the deuterium gas will have a pronounced heterogeneity in energy due to the spread of energy in the neutron beam released in the Be-D nuclear reaction by the A.C. accelerating voltage and the large irregular scattering from the surrounding walls. The distribution-in-energy curve should, therefore, be more or less flat with slight random variations. A prominent peak in the curve can only be due to an anomaly arising from a resonance effect in an excited state of the intermediate compound nucleus formed in the scattering process or may arise from the presence of a distinct homogeneous group in the incident neutron beam. The existence of an anomaly due to an excited He\(^6\) state in neutron-helium scattering has been established recently\(^7\) in a number of experiments. Assuming that the interaction between the neutron and the deuteron can be represented by a potential (radius of well equal to 4.5 \times 10^{-13} \text{ cms.}), Massey and Mohr deduced\(^8\) that the elastic scattering with neutrons having a de Broglie wave length in the neighbourhood of 6.78 \times 10^{-13} \text{ cms.} is low at high energies, rises to a maximum at about 0.8 Mev. neutron energy and falls off again for smaller energies. The peak at 0.7 Mev. in the distribution-in-energy curve in Fig. 3 may arise from this type of “Ramsauer effect” as deduced by Massey and Mohr for the scattering of medium fast neutrons by deuterons. The smaller peak, presumably, arises from the peak energy of the low energy group of neutrons released in the Be-D nuclear reaction. Assuming the approximate validity of the equation deduced by Baldinger, Huber and Staub\(^9\) for the distribution in energy of the primary neutrons in terms of the energy distribution of the recoil nuclei, the curve in Fig. 4 has been plotted using the cross-section values given by Massey and Mohr (loc. cit.). The curve indicates that the neutron beam which gets scattered in the ionisation chamber does have a wide spread of energy.
Recently Buckingham and Massey\textsuperscript{10} find that the scattering cross-section, in the case of neutron-deuteron scattering, will have a maximum value between zero and 1.85 Mev. neutron energy, on the basis of assumption of mixed exchange type of forces. A fuller discussion in regard to the peak at 0.7 Mev. energy in the distribution-in-energy curve, in our experiments, will be given in another paper.

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**Summary**

The results of an experimental study of the elastic scattering of medium fast neutrons in deuterium gas is presented in the paper. If a potential interaction between the neutron and the deuteron is assumed, the results would indicate a fairly large value for the range of interaction. Certain conclusions arrived at by Buckingham and Massey on the assumption of mixed exchange type of forces are borne out in the present experimental study.

**REFERENCES**

Fig. 2