EXPERIMENTAL STUDY OF THE DEUTERON INDUCED DEUTERON BREAK-UP AT LOW ENERGY[1]

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The quasi-free scattering process has been studied in the $d + D \rightarrow n + p + D$ reaction at 6 deuteron energies between 6.77 MeV to 11.7 MeV in steps of 1 MeV. Coincident events between neutron and charged-particle pulses (emitted protons or deuterons) have been recorded at angles of $\Theta_p = \Theta_d = 19.5°$ and $\Theta_n = 330°$. Some calculations using the plane wave approximation account for the shape of the experimental cross sections but not for their magnitude. Two kinds of nucleon-nucleon forces are used and discussed.

It is well known that, in the $d + D \rightarrow n + p + D$ reaction, the contribution of the final-state interaction process is weak for the deuteron-proton and neutron-deuteron pairs [1—3]. This is principally due to the fact that the phase shifts are, between 0 and 3 MeV, slowly varying with the relative energy of the nucleon-deuteron pair. It may be assumed that the quasi-free scattering is the predominant process of this reaction. This process is responsible for a strong peak centred at the minimum unobserved particle laboratory energy. In the theoretical interpretation of the experimental data the impulse approximation is frequently used [2—7]. Corey et al. [7] have made measurements, for this reaction, at the incident deuteron energy of 20.7 MeV. Their results have been compared with theoretical calculations based on both the P. W. B. A and the D. W. B. A approximations. The first one has been found to account, at best, for the shape of the experimental cross sections but not for their magnitude.

It was interesting to test the validity of these approximations at a lower energy. Two kinds of potentials were used: a zero range potential $V_0\delta(\mathbf{r})$ [$V_0 = -1100$ MeV f m^3] and a finite range potential having a gaussian shape $V_G e^{-\lambda r^2}$ [$V_G = -50$ MeV, $\lambda = 0.4$ f m^{-2}]. Our measurements were made under geometrical conditions where the quasi-free scattering is enhanced. We have thus recorded coincident events between protons and deuterons at an angle of 19°30 and neutrons at an angle of 330°. The experiments have been carried out at 6 deuteron energies from 6.77 to 11.7 MeV in steps of 1 MeV.

The incident deuterons were accelerated by the Tandem Van de Graaff accelerator installed at the Centre d'Études de Bruères-le-Châtel. To avoid a large number of random coincidences the average current was limited to 7 nA. A deuterium gas target inside a scattering chamber was used [8].

The neutron detector was set 215 cm from the target. The charged particles were detected through a window in the gas-target holder by a surface-barrier diode (1500 μm thick) at 10 cm from the center of the gas cell. The time-of-flight difference between the neutron and the charged particle was measured with a time-to-amplitude converter. The linear pulse height from the output was recorded simultaneously with the charged particle energy. In the data reduction, these informations were used to distinguishebetween the emitted protons and deuterons. For a given energy, the protons and the deuterons correspond to two time-of-flight peaks emerging above the underlying background. The bi-parameter background surface was obtained by successive smoothing of the data away from the peak regions and subtracted channel by channel from the total surface. Then peak areas were determined. These data have been corrected for neutron attenuation in the scattering-chamber wall and for the efficiency of the neutron detector. Moreover the mean energy loss of the charged particles in the gas target was taken into account.

We present, in Figs. 1, 2, our experimental results related tó the (d, n) and (p, n) coincident spectra. The error bars are obtained by adding quadratically the statistical and the neutron efficiency uncertainties. This last error has been evaluated to 5 % between 2 and 12 MeV neutron energies. Between the neutron detector threshold (500 keV) and 2 MeV it increases for decreasing neutron energies and relates a value of 20 % at 500 keV.

We observe, in the experimental spectra, a strong peak centred at the minimum laboratory energy of the unobserved particle. The measured full-width at half maximum has been found to increase slowly with incident energy.

The solid lines are related, in Figs. 1, 2, to our theoretical calculations. They were made using a similar method to that proposed by Corey et al. [7]. The adopted hypotheses

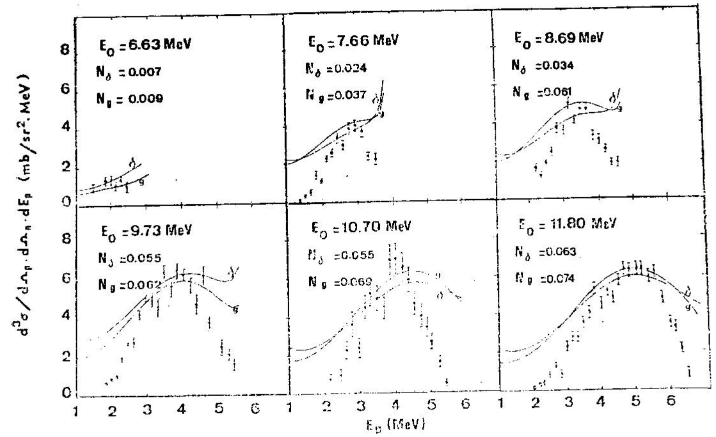

Fig. 1. Analysis of the proton spectra from a $D + D$ break-up reaction at 6 deuteron energies. The experimental data are given by the dots and errors bars. The solid lines give the predictions for the spectra according to thé calculations outlined in the text. The respective values for the normalization coefficient deduced are indicated in the figure.

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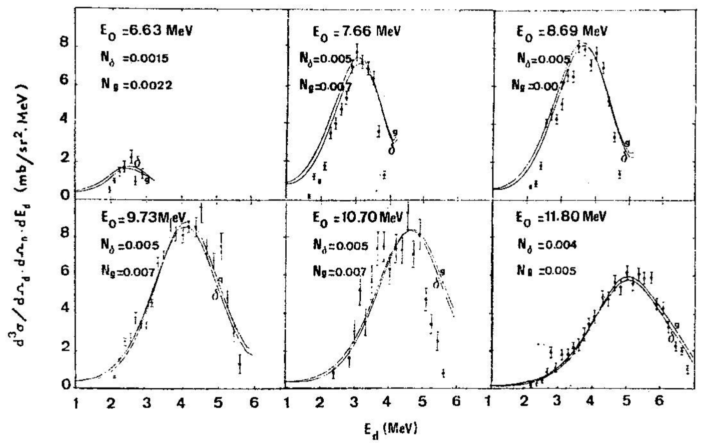

Fig. 2. Analysis of the deuteron spectra from the $D + D$ break-up reaction. For the rest, the legend is the same as for Fig. 1.

may be summed up thus: The P. W. B. A without including any final-state interaction was adopted. The spacial deuteron wave function was a Hulten function. The in-going and out-going wave functions were antisymmetrized relative to the interchange of two nucleons assuming isospin conservation. All the calculations were made in the laboratory system. With central potentials, the isospin, spin and spatial parts of the ten matrix elements were separated. The various reaction probabilities were then deduced: $T^{(t)}(0)$, $T^{(t)}(1)$, $T^{(t)}(2)$, $T^{(s)}(1)$. They are defined by the spin value (0, 1, 2) of the exit channel and by that of the neutron-proton unbound pair (triplet or singlet). They are presented, in Fig. 3, for a 10.7 MeV incident deuteron energy and for the (d, n) coincidence spectrum. Near the deuteron energy of 2 MeV we observe a serious decrease of the matrix elements $T^{(t)}(1)$ and $T^{(t)}(2)$. The cross section is given in (n-charge particle (cp)) coincidence by:

$$\frac{d^3\sigma}{d\Omega_n \, d\Omega_{cp} \, dE_{cp}} = \frac{2\pi}{\hbar} \sqrt{\frac{M}{E_0}} \sum_{i,f} |T|^2 \varphi_{cp}$$

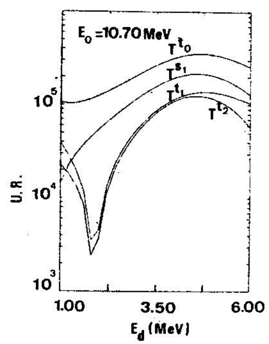

Fig. 3. P. W. B. A reaction probabilities for (d, n) coincidences at a 10.7 MeV deuteron energy. The finite range potential is used.

$$\sum_{i,f} |T|^2 = \frac{1}{9} \left[|T^{(t)}(0)|^2 + 3|T^{(t)}(1)|^2 + 3|T^{(s)}(1)|^2 + 5|T^{(t)}(2)|^2 \right],$$

where M is the nucleon mass, E_0 the incident deuteron energy and ϱ_{cp} the related state density. For the (d, n) coincidence spectrum, the agreement of the shape of the calculated cross sections with the experimental one is fairly good in the whole energy range. On the other hand, for the (n, p) coincidence spectrum, the agreement is better when the energy increases. Moreover a gaussian N-N potential gives a more reliable description of the reaction.

The ratios N of the experimental peak cross section to the calculated one have been deduced, for the two investigated potentials. The values of these two ratios are given in Figs. 1 and 2.

The quasi-free scattering process has been studied from the $d + D \rightarrow n + p + D$ reaction at 6 energies between 6.77 MeV to 11.7 MeV in step of 1 MeV. It has been proved that even in this energy range the plane wave approximation accounts fairly well for the shape of the experimental cross sections.

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