Deuteron-Deuteron Reaction at High-Energy

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Recently Godfrey measured the differential cross section for the process $d + d \rightarrow {^{3}}He + p$, using the deuterons of 190 Mev from the Berkeley synchrocyclotron. This is one of the simplest processes in the high-energy stripping or pickup reactions. He showed that it was inadequate to explain the angular distribution merely in terms of the pure stripping (or pickup). So far two mechanisms have been proposed about the pickup process in the high-energy nucleon bombardment on nuclei. One of them leads to the direct process, as proposed by Chew and Goldberger, which contributes strongly to the small angle part of the angular distribution of the deuterons; and the other to the indirect process, so called by Bransden, contributing chiefly to its large angle part. As the nuclei concerned here are of simple constitution it will be expected that the above process can be treated from the unified standpoint. The main purpose of this note is to study the behavior of the differential cross sections for the above process from this respect.

Using the Born approximation and the charge-independent Serber force between two nucleons, we calculated the differential cross section in the center-of-mass system. We obtained the following expression:

$$d\sigma(\theta) = 4K/3k(3M/8\pi\delta)^2[2/3 \cdot [I(\theta) - I(\pi - \theta)]^2$$

$$+ 1/3 \cdot [I(\theta) + I(\pi - \theta)]^2 + 1/12 \cdot (1 + 3q)^2 [J(\theta)$$

$$+ J(\pi - \theta)]^2$$
Here $k$ and $K$ are the wave numbers of the incoming deuteron and the outgoing triton, respectively, in the center-of-mass system; and $\theta$ is the angle between $k$ and $K$. $q$ is the ratio of the singlet to the triplet potential depth in the neutron-proton interaction. It will be more convenient to consider the inverse process $H^3+p\rightarrow d+d$ to see the physical meanings of the integrals $I$ and $J$, because the matrix element remains the same as the original.

As the result of the interaction between the incoming proton and one nucleon in the triton, there come out two cases where these two interacting nucleons end up in the same deuteron or in different deuterons. The former corresponds to the direct process mentioned above, while the latter is similar to the indirect process. The integral $I$ shows the interaction matrix element of the former case and $J$ that of the latter one. Therefore, we may call $I$ and $J$ the direct integral, respectively.

Using the Yukawa potential, we calculated both integrals under the assumptions of the Hulthén wave function for the deuteron and the Irving wave function ($n=0$) for the triton. Both integrals had to be solved with numerical integrations. The cross sections consist of three contributions from direct, indirect and interference term.

Fig. 1. The angular distribution of the triton in the center-of-mass system. --- Yukawa potential ($r_o=1.18\times10^{-13}\text{cm}, V_0''=67.8\text{ Mev}, q=0.686$); --- Gaussian potential ($r_o=1.94\times10^{-13}\text{cm}, V_0''=45.0\text{ Mev}, q=0.578$).

Fig. 2. The angular dependences of the contributions to the cross sections from (a) direct, (b) indirect and (c) interference term. --- Yukawa potential, --- Gaussian potential.

The direct term is dominant at the small angle part of the angular distribution, and negligible at the large angle part. Then the slope of its curve is greater than that of the experimental curve. On the contrary, the indirect term shows the appreciable contribution at these large angles, and thereby the slope of the resultant curve becomes much closer to that of the experimental curve. The interference term shows the considerable effect at the intermediate angles.

The details are shown in Figs. 1 and 2. The theoretical value of the total cross section (18.2 mb) is much larger than the experimental value (4.1 mb) in our approximations. By the way, the calculations with the Gaussian potential were also carried out, because both integrals could be analytically solved. The results are also shown in the same figures for comparison. The theoretical value of the total cross section (3.5mb) is close to the experimental value, but the slope of the angular distribution is much greater than that of the experimental curve.