ANGULAR DISTRIBUTION OF PROTONS EMITTED IN THE REACTION D(n, p) 2n

V. K. VOĬTOVETSKIĬ, I. L. KORSUNSKIĬ, and Yu. F. PAZHIN

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The energy spectrum of protons emitted in the D(n, p)2n reaction is measured near the upper limit at angles of 4.5°, 10°, 15°, and 20°.

In previous work [1] on the determination of the neutron-neutron scattering length a_{nn}, we measured the energy distribution of protons emitted in the inelastic scattering of neutrons by deuterium. The measurements were made at an angle of 0° (the mean angle ϑ_0 of the protons with respect to the incident neutrons was 4.5°) in the vicinity of the peak due mainly to interaction of the neutrons in the final state. The spectrum was described by an expression for the differential cross section obtained from analysis of the Feynman diagrams1) corresponding to this process. In the proton-energy regions studied, where the relative internal momentum of the neutrons $\hbar\mathbf{f}$ is small (the relative energy of internal motion of the neutrons $E_{nn} < 1$ MeV), the reaction amplitude was presented in the form of a sum of contributions from the individual graphs, in which the part of the quadratic diagram contribution not containing (with an accuracy up to the small quadratic terms in f) an f-dependence connected with the primary interaction, together with the contribution of the more complex diagrams with a large number of internal lines, is expressed by the product of the neutron-neutron scattering amplitude and an experimental constant.

In the present work we present for comparison with theory the measured angular distribution of protons in the same region of the spectrum2). The experimental method is the same as that described in our earlier paper.[1]

The $T(d, n)He^4$ reaction was used as the source of neutrons. The mean neutron energy was 13.9 MeV. The neutron intensity was monitored by counting α particles. The radiator was a deuterated polyethylene film 4.3 mg/cm^2 thick. The proton spectra were determined at different angles with a telescope consisting of three scintillation counters. (The experimental apparatus has been described in detail by us previously.[4])

The relatively greater energy losses in the first two scintillators allowed us to obtain non-overlapping energy loss distribution curves for deuterons and protons and, by analyzing the summary pulses of the first two counters, to separate the two kinds of particles completely.

Figure 1 shows the proton energy distribution measured for laboratory angles ϑ_0 of 4.5°, 10°, 15°, and 20°, corresponding to center-of-mass angles $\vartheta_{0\,c.m.}$ of 8°, 17.3°, 25.7°, and 30.5°.

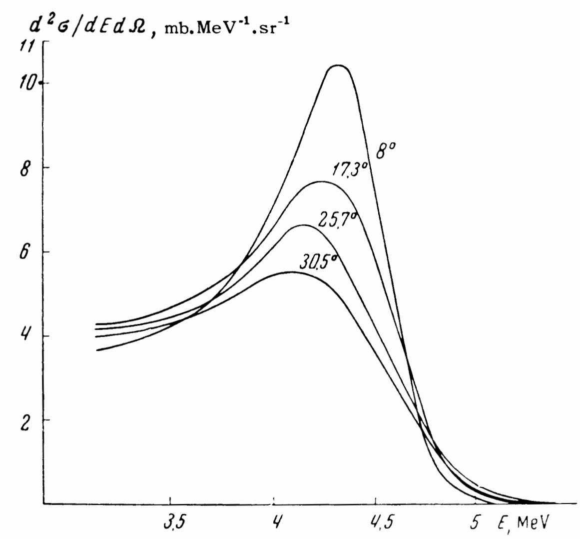

FIG. 1.

The proton intensity in the peak drops with the transition to larger angles. The increase of angle ϑ_0 changes to a certain extent the entire character of the spectrum in the energy regions studied. For $\vartheta_0 < 5°$ the quantity $\mathbf{q} = (\mathbf{k}_0 - \mathbf{k})/2$ is negligibly small ($\hbar\mathbf{k}_0$ is the initial momentum of the neutron and $\hbar\mathbf{k}$ is the proton momentum). The f-dependent part of the contribution to the amplitude from the quadratic diagram is

1)Komarov and Popova[2] have shown that summation of an infinite series of nonrelativistic perturbation theory diagrams leads to an equation for the wave function of the system.

2)The angular distribution of protons in the reaction D(n,p)2n has been experimentally determined also by Ilakovac et al.[3]

$$A_2'^{nn} \sim \frac{1}{\alpha_{nn} + if - {}^1/_2 r_{0s}(\alpha_{nn}^2 + f^2)} \frac{1}{\alpha_t - if}$$

where $\alpha_{nn} = 1/a_{nn}$, $\alpha_t = 1/a_t$; a_t is the triplet np-scattering length, and r_0 is the singlet effective radius. At larger values of ϑ_0 the quantity q cannot be neglected and for $A_2'^{nn}$ it is necessary to use the expression

$$A_2'^{nn} \sim \frac{1}{\alpha_{nn} + if - {}^1/_2 r_{0s}(\alpha_{nn}^2 + f^2)} \frac{1}{2q} \left[\tan^{-1} \frac{2\alpha_t q}{\alpha_t^2 + f^2 - q^2} + \frac{i}{2} \ln \frac{\alpha_t^2 + (f+q)^2}{\alpha_t^2 + (f-q)^2} \right].$$

With an increase of ϑ_0, besides the rapid drop of intensity in the peak at the upper limit of the spectrum, the intensity at smaller energies should rise and at large values of ϑ_0 should appear as a second broad peak corresponding to the condition $f = \pm q$.[3)] The angular dependence of the cross section for production of protons should be flatter in the wide energy interval near the upper limit of the spectrum than in the peak due to the neutron-neutron final-state interaction. This is confirmed experimentally. The corresponding dependence for the center-of-mass energy interval 3.2-4.7 MeV is shown[4)] in Fig. 2, which also shows the differential cross section for neutron production in the symmetrical reaction D(p, n)2p. The latter was calculated for the same energy interval from the data of Wong et al.[6] The neutron production cross section is roughly 1.6 times less in absolute value than the proton production cross section. This decrease is due to the effect of the Coulomb interaction of the proton and the deuteron, which is expressed by the transparency coefficient, and to the effect of the Coulomb interaction of the protons.

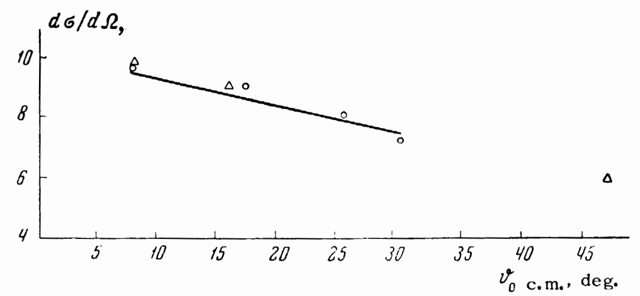

FIG. 2. Angular dependence (c.m.) of the cross section for production of protons in the reaction D(n,p)2n (○), and of neutrons in the reaction D(p,n)2p (Δ), for the energy interval 3.2-4.7 MeV. The cross sections for the D(p,n)2p reaction have been multiplied by a factor of 1.6. The solid curve corresponds to the theoretical cross section.

It can be seen from Fig. 2 that experimental angular distributions for the D(n, p)2n and D(p, n)2p reactions in the energy regions studied are in satisfactory agreement with each other and with theory.

3)This structure is weakly expressed in the spectra shown in Fig. 1 because of the small initial particle energy for which fulfillment of the condition $f = \pm q$ for relatively large values of f occurs at large values of ϑ_0 (approximately, $f \sim k_0(1 - \cos \vartheta_{0\,\mathrm{c.m.}})^{1/2}$ for $f = q$), and is masked by the effect of the final-state neutron-proton interaction. The structure appears distinctly in the proton spectrum from the D(p,n)2p reaction obtained by Stairs[5] for an initial proton energy $E_0 = 158$ MeV. For this value of initial energy the second maximum is observed at angles of 15-20°. The effect of the final-state interaction at $E_0 = 158$ MeV is limited to the small energy regions.

4)The broadening of the energy region in which we use for the differential cross section an expression that is accurately valid when $E_{nn} < 1$ MeV, to include angular dependences over a wide energy interval, does not involve a significant loss of accuracy.

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