Letters to the Editor

ANGULAR DISTRIBUTION OF NEUTRONS IN THE REACTION C^{13} (d, n) N^{14}

T. L. ABELISHVILI, T. G. GACHECHILADZE and O. M. MDIVANI

Tbilisi State University; Institute of Electronics, Automation, and Telemechanics, Academy of Sciences, Georgian S.S.R.

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In the present note we give the results of a calculation of the angular distribution of neutrons in the reaction C^{13} (d, n) N^{14}, studied experimentally by Green, Scanlon, and Willmott[1] for an incident deuteron energy of 0.86 Mev. They managed to obtain four groups of neutrons with respect to energy (g_0, g_1, g_2, and g_3). The first group corresponds to the final N^{14} nucleus in its ground state, and the remainder to transitions to the first three excited states of the final nucleus.

As is well known, the differential cross section for the reaction, taking exchange effects into account, takes the form:[2]

$$\frac{d\sigma}{d\Omega} = c(E)\,|\,i^{l_1} G_D(K_1)\, j_{l_1}(k_1 R_1) - \frac{\Lambda_2}{\Lambda_1}(-1)^l\, i^{l_2} G_H(K_2)\, j_{l_2}(k_2 R_2)|^2.$$

Here l_1 and l_2 are the angular momenta of the absorbed particles corresponding to normal and "heavy particle" stripping; l describes the relative orbital angular momentum of the odd neutron in the target nucleus; R_1 and R_2 are characteristic interaction radii; Λ_2/Λ_1 is the ratio of the reduced widths; j_l are the spherical Bessel functions of order l;

$$G_i \approx 2\sqrt{2\pi\alpha_i}/(\alpha_i^2 + K_i^2) \quad (i = D, H),$$
$$K_1^2 = k_n^2 + \tfrac{1}{4} k_d^2 - k_n k_d \cos\vartheta,$$
$$k_1^2 = k_d^2 + (M_{12}/M_{14})^2 k_n^2 - 2(M_{12}/M_{14})\, k_n k_d \cos\vartheta,$$
$$K_2^2 = k_n^2 + (M_n/M_{13})^2 k_d^2 + 2(M_n/M_{13})\, k_n k_d \cos\vartheta,$$
$$k_2^2 = k_d^2 + (M_d/M_{14})^2 k_n^2 + 2(M_d/M_{14})\, k_n k_d \cos\vartheta.$$

In these formulas k is the wave number, M the mass, and ϑ the scattering angle in the center-of-mass system.

Besides exchange effects, a significant part is played by the process of spin flip of the liberated nucleon.[3] Taking this effect into account both for normal and "heavy particle" stripping leads in our case to the formula

$$\frac{d\sigma_{D,H}}{d\Omega} = \frac{1}{4\pi^2\hbar^4}\frac{k_n}{k_d}\frac{M_n M_{14}}{M_n + M_{14}}\frac{M_d M_{13}}{M_d + M_{13}} \times \sum_{l,m}\Big(\sum_{J,j}(2J+1)\Big|\int \Psi^{M*}_{Jj_f 1/2} f_{D,H}(\sigma_n, \xi)\Psi^M_{Jjl}\,d\tau\Big|^2\Big) \times \frac{|\alpha_{D,H}(l,m)|^2}{2l+1},$$

where

$$\alpha_D(l,m) = \int \exp(-i\mathbf{k}_n\mathbf{r}_n)\,\delta(r_n - R_1) \times \exp\Big\{\frac{i}{2}\mathbf{k}_d\Big[\mathbf{r}_n + \mathbf{R}_1\frac{M_{13}+2M_n}{M_{13}+M_n}\Big]\Big\} \times \Phi_d\Big(\Big|\mathbf{R}_1\frac{M_{13}}{M_{13}+M_n} - \mathbf{r}_n\Big|\Big) Y_l^{m*}(\Omega_p)\, d\Omega_p d\mathbf{r}_n,$$

$$\alpha_H(l,m) = \int \exp(-i\mathbf{k}_n\mathbf{r}_n)\,\delta(r_n - R_2)\exp\Big\{-\frac{i\mathbf{k}_d}{M_{13}}\Big[M_n\mathbf{r}_n + M_{12}\Big(1 + \frac{M_n}{M_d + M_{13}}\Big)\mathbf{R}_2\Big]\Big\}\Phi_{C^{13}}\Big(\Big|\mathbf{R}_2\frac{M_d}{M_d + M_{12}} - \mathbf{r}_n\Big|\Big) \times Y_l^{m*}(\Omega)\, d\Omega\, d\mathbf{r}_n,$$

Φ_d and $\Phi_{C^{13}}$ are the internal functions of the deuteron and the odd neutron in C^{13}. For normal stripping $\mathbf{J} = \mathbf{j}_f + \vec{\tfrac{1}{2}}$, $\mathbf{j} = \vec{\mathbf{j}}_i + \vec{\mathbf{l}}$, and for "heavy particle" stripping $\mathbf{J} = \mathbf{j}_f + \vec{\tfrac{1}{2}}$, $\mathbf{j} = \vec{\mathbf{l}} + \vec{\tfrac{1}{2}}$. The subscripts D and H correspond to normal and "heavy particle" stripping.

The calculations show that: (1) the data corresponding to the transition to the ground state can be explained by assuming that the reaction is described by the theory of Butler with exchange effects taken into account (see Fig. 1); (2) that the data corresponding to the transition to the first two excited states is understood if we take the spin-flip process into account for both kinds of stripping without taking account of their interference, since the amplitudes for the two processes are in fact not separated (see Figs. 2 and 3); (3) in the case of a transition to the third excited state, the spin-flip process occurs only for the "heavy particle" stripping, with interference not taken into account (see Fig. 4).

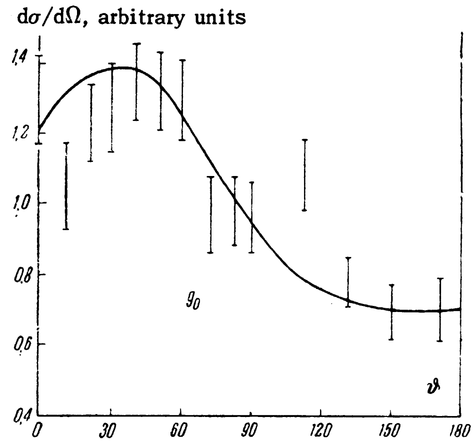

FIG. 1

Neutron group	Excitation energy, Mev	Spin of N^{14}	l_1	l_2	$10^{13} R_1$, cm	$10^{13} R_2$, cm	Λ_2/Λ_1
g_0	0.00	1^+	1	0	4.5	4.5	0.47
g_1	2.31	0^-	0	0	6.0	6.0	—
g_2	3.90	1^+	0	0	5.0	5.0	—
g_3	4.80	$0^-, 1^-$	0	0	6.5	7.5	—

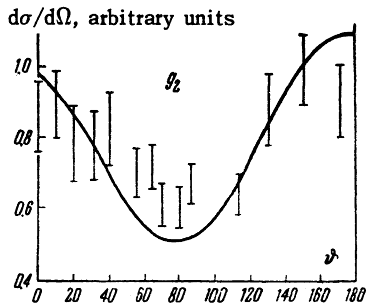

FIG. 2

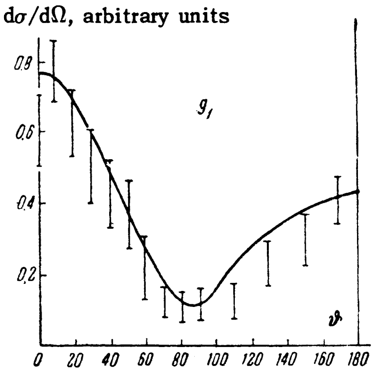

FIG. 3

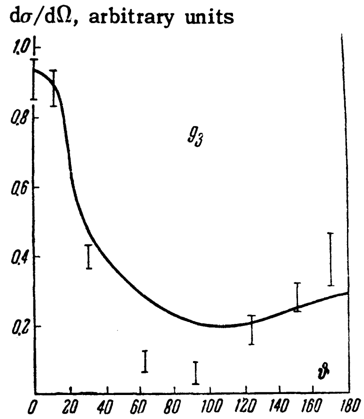

FIG. 4

The values of the parameters used for the calculation are given in the table; $\alpha_D = 0.23 \times 10^{13}$ cm^{-1}, $\alpha_H = 0.47 \times 10^{13}$ cm^{-1}.

[1] Green, Scanlon, and Willmott, Proc. Phys. Soc. **A68**, 386 (1955).

[2] G. Owen and L. Madansky, Phys. Rev. **105**, 1766 (1957).

[3] J. E. Bowcock, Phys. Rev. **112**, 923 (1958).

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POSSIBLE INFLUENCE OF NUCLEON STRUCTURE IN HIGH ENERGY INTERACTIONS

Zh. S. TAKIBAEV

Institute for Nuclear Physics, Academy of Sciences, Kazakh S.S.R.

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CLARIFICATION of the relation between the angular distribution of shower particles and their energy spectrum could provide a means to study the inner structure of the nucleon. In several instances it is more convenient to consider the distribution in the Lorentz-invariant transverse momenta instead of the energy spectrum.

In the majority of showers[1] the average value of the transverse component of the momentum amounts to $\sim (1-1.5)\, m_\pi c$, where m_π stands for the mass of the pion. In his papers[2] devoted to the problem of multiple production of mesons, Heisenberg observed that the average value of the transverse momentum of particles produced in the high energy region should be of just that order of magnitude.

If the primary particle is sufficiently energetic to penetrate inside the nucleon, then depending on the initial conditions of the interaction (i.e., depending on the values of the impact parameter), the production of heavier mesons, e.g., K mesons, is possible and this process probably occurs in a volume characterized by the dimension $\sim \hbar/m_K c$. Such a phenomenological treatment (a different approach is given by Jastrov[3]) is discussed in great detail from various points of view in a series of papers by Blokhintsev et al.[4]