DIRECT INTERACTION IN REACTIONS WITH EMISSION OF TWO NUCLEONS

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IN collisions of a nucleon having an energy larger than 10 Mev with a nucleus, a direct interaction of the incident nucleon with one of the nucleons of the nucleus is possible, which leads to the emission of both nucleons. This process was found experimentally, e.g., in reactions (n, 2n), (p, p′n)[1,2] and others. The angular distribution for one of the produced nucleons and the total cross section for such processes were calculated by Austern et al.[3] and Mamasakhlisov,[4] who assumed the wave functions of nucleons produced by the reactions to be plane.

We consider here the momentum angular distribution of the c.m.s. of the two nucleons produced in a direct interaction of an incident nucleon with a nucleon of the nucleus in reactions of the type (n, 2n), (p, 2p), (n, n′p), (p, p′n). The calculation was carried out under the following assumptions: The wave function of the incident nucleon (n_0) is assumed to be plane. The wave function of the nucleon (n_1) inside the nucleus with which the incident nucleon interacts is based on the shell model, assuming LS coupling. The interaction between nucleons $V_{n_0 n_1}$ is taken in the form of a rectangular well with radius ρ_0, while ψ_{2n}, the wave function of the system of two nucleons which takes into account the interaction of nucleons in the final state for $\rho > \rho_0$, is assumed to be of the form[5]

$$\psi_{2n}^{(1)} = \exp(i\mathbf{f}\boldsymbol{\rho}) + a\rho^{-1}\exp(-if\rho),$$

where $\mathbf{f}$ is the wave vector of the relative motion of the nucleon n_0 and the nucleon n_1, and $a = -(\alpha - if)$ is the scattering length $[\alpha = (M\epsilon\hbar^{-2})^{1/2}$, where ϵ is the interaction energy of the two nucleons]. Inside the interaction region $(\rho < \rho_0)$ the radial part of the wave function of the system of two nucleons is of the form $\psi_{2n}^{(2)} = A\rho^{-1}\sin k'\rho$, where $\mathbf{k}'$ is the wave vector with respect to the motion of n_0 and n_1 inside the potential well. A and k' are determined from the junction of the functions $\psi_{2n}^{(1)}$ and $\psi_{2n}^{(2)}$ at the point $\rho = \rho_0$. The interaction of emitted nucleons with the residual nucleus is neglected.

Under the above assumptions, the differential cross section for the process under consideration can be written in the form

$$\frac{d\sigma}{d\Omega} = \frac{M_0 M_{2n}}{(2\pi\hbar^2)^2}\frac{k_{2n}}{k_{n_0}}\frac{1}{(2s_0+1)(2J_1+1)}|I|^2, \qquad (1)$$

where M_0 and M_{2n} are the reduced masses of the incident nucleon and the system of two nucleons, $\mathbf{k}_{n_0}$ is the momentum of the incident nucleon, $\mathbf{k}_{2n}$ is the momentum of the c.m.s. of the two nucleons, s_0 is the spin of the incident nucleon, J_1 is the total moment of the original nucleus, $|I|^2$ is the square of the matrix element summed over all final states, and

$$I = \sqrt{n}\langle l^n, \alpha_1 L_1 S_1 J_1 T_1; \; \mathbf{k}_{n_0} s_0 | V_{n_0 n_1} | l^{n-1}, \alpha_2 L_2 S_2 J_2 T_2; \; \mathbf{k}_{2n}\mathbf{f}_{2n} s_{2n}\rangle, \qquad (2)$$

where index 1 refers to the original nucleus, index 2 to the final nucleus, s_{2n} is the spin of the system of the two nucleons, and T is the isotopic spin.

The wave function of nucleon n_1 is separated from the wave function of the initial nucleus by means of the parentage and the Clebsch-Gordan coefficients. The summation over the magnetic numbers of the final state is carried out by a method similar to that of reference 6. For the case $E_{n_0} \leq 20$ Mev, the basic contribution to the differential cross section will be due only to the s wave in the partial-wave expansion of the wave function of the relative motion of the two emitted nucleons. From the Pauli principle, the spin function should be antisymmetric and $s_{2n} = 0$ for two identical nucleons produced, e.g., as a result of the reactions (n, 2n) and (p, 2p). For an event for which two different nucleons are emitted, s_{2n} may be 0 and 1; consequently, in constructing the angular distribution, one has to take into account two possible spin states. After integrating the matrix element over the variables of the final nucleus r_{n_1} and ρ, the square of the matrix element will be a function of k_{2n}. For a given angle between k_{2n} and k_{n0}, the value of k_{2n} is related to the value of the momentum of the recoil nucleus by the conservation of momentum law. Consequently, the square of the matrix element must be integrated over the whole range of variation of k_{2n} with the kinetic energy of the residual nucleus.

The curves of the angular distribution of the vector k_{2n} for the reaction $Be^9(n, 2n)Be^8$ were calculated numerically. The following data were used in the calculation: $E_{n_0} = 14$ Mev, the excitation energy of the Be^8 nucleus equal to 2.9 Mev, and $\epsilon = 70$ kev. The integration was carried out over a range of variation of the kinetic energy of

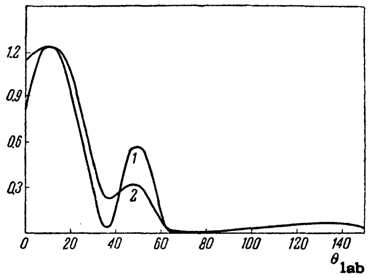

FIG. 1

Be^8 from 0.5 to 2 Mev. The calculated curves of the angular distribution k_{2n} for $\rho = 1 \times 10^{-13}$ cm (curve 1) and $\rho = 2.8 \times 10^{-13}$ cm (curve 2) are shown in Fig. 1. The histogram of the angular distribution of the vector k_{2n} obtained experimentally by using nuclear emulsions,[7] where the reaction was identified by the particle tracks produced as a result of the decay of the Ne^8 nucleon, is shown in Fig. 2. The peak for small angles was not found in the experiment. This may possibly be explained by the fact that we probably omitted those stars, in which k_{2n} is directed forward with respect to the direction of the incident neutrons and the kinetic energy of the Be^8 nucleus is smaller than 1 Mev, i.e., when the tracks of α particles produced in the decay of Be^8 are difficult to observe in the emulsion. If one constructs the theoretical curve of the angular distribution of the vector k_{2n} for the variation of the kinetical energy of Be^8 in the range 1 to 2 Mev, then the peak for small angles disappears (see Fig. 2, solid curve) and an approximate agreement between the experimental histogram and the calculated curve can be seen (curve for $\rho_0 = 2.8 \times 10^{-13}$ cm).

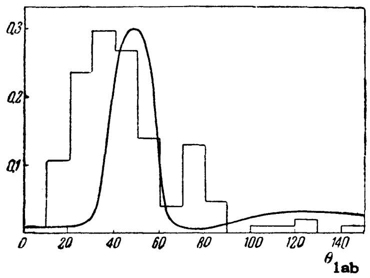

FIG. 2

Numerical calculations of the angular distribution of an event in which a bound bi-neutron is emitted yield the usual Butler-type curve with a sharp maximum at 0°, and with first minimum at 30°. Evidently, this curve cannot be compared with the histogram since, as has been shown above, it is difficult to observe in the emulsion events with emission of two neutrons in the forward direction.

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ON THE INFLUENCE OF THE ISOBARIC STATE OF A NUCLEON ON THE ELECTRON-NEUTRON INTERACTION

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It is well known that the experimentally-found large value of the electromagnetic radius of the proton on one hand, and the very small depth of the well of the electrostatic electron-neutron interaction on the other, lead to considerable difficulties in interpretation of these data.

Since it would have been very undesirable to abandon the idea of charge independence of strong interactions, the assumption has been proposed that the usual electrodynamics ceases to be correct at distances of the order of 10^{-14} cm. It could then be understood why large electromagnetic dimensions are observed for a proton for a small depth of the well $V_0^{(S)}$ of the electrostatic e-n interaction without abandoning the charge independence of meson-nucleon interactions.