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On the Nuclear Reaction Be^9 (pd) Be^8

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WE know that the nucleus of Be^9 can be regarded as consisting of Be^8 as a core, with an unpaired neutron moving in its field. This model proved to be quite satisfactory in connection with the photo- and electrodisintegration of this nucleus[1,2]. On the basis of this model, the Be^9 $(pd)Be^8$ reaction can be considered to be the result of the direct interaction of a proton and the unpaired neutron. The mechanism of this reaction then appears to be the following: an incident proton interacts with the unpaired neutron to form a deuteron, which escapes from the nucleus, leaving the Be^8 nucleus in its ground state. We here neglect particle spins, the Coulomb interaction and the recoil of the Be^8 nucleus.

The interaction between the proton and the nuclear neutron, whose radius vectors are designated by $\mathbf{r}_2$ and $\mathbf{r}_1$, respectively, is taken in the form of a Yukawa potential

$$V(r) = -g^2 r^{-1} e^{-\varkappa r}, \qquad (1)$$

where $r = |\mathbf{r}_1 - \mathbf{r}_2|$. For the wave function $\psi(\mathbf{r}_1)$ of the unpaired neutron in the Be^9 nucleus we take an expression given in Ref. 1. The wave function $\psi(\mathbf{r}_2)$ of the incident proton is taken in the form of a plane wave with the wave vector $\mathbf{k}$ normalized to unit flux. The wave function of the deuteron with wave vector $\mathbf{k}'$ is

$$\psi_d(\mathbf{r}_1, \mathbf{r}_2) = (2\pi\hbar)^{-3/2} e^{-ik'(\mathbf{r}_1+\mathbf{r}_2)/2}\, \Phi(r), \qquad (2)$$
$$\Phi(r) = \sqrt{\alpha_1/2\pi}\, r^{-1} e^{-\alpha_1 r},$$

where $\Phi(r)$ is the wave function of the internal state of the deuteron.

The differential cross section of the process that we are considering, as calculated by the usual equation of perturbation theory, is given by

$$\frac{d\sigma}{d\omega} = \sqrt{2\left(1+\frac{Q}{E_p}\right)}\, 48 a^2 \frac{\mu^2 g^4 r_0^2 \alpha_1 r_0}{\beta r_0 \hbar^4} \qquad (3)$$
$$\times r_0^2 (|\mathbf{k}'/2 - \mathbf{k}|\, r_0)^{-2} \operatorname{arctg}^2 \frac{\left|\frac{\mathbf{k}'}{2} - \mathbf{k}\right| r_0}{\gamma r_0}$$
$$\times [\varphi(E_p, \vartheta) + (\beta/\alpha)^2 \sin\beta r_0\, e^{\alpha r_0} J(E_p, \vartheta)]^2;$$

$$\varphi(E_p, \vartheta) = \frac{\beta r_0 \sin(\beta+q) r_0}{2(\beta+q) r_0} + \frac{\beta r_0 \sin(\beta-q) r_0}{2(\beta-q) r_0}$$
$$+ \frac{\cos(\beta+q) r_0 - \cos(\beta-q) r_0}{2 q r_0},$$

$$J(E_p, \vartheta) = \int_{r_0}^{\infty} \frac{(1+\alpha r)}{r} e^{-\alpha r} \cos qr\, dr$$
$$- \frac{1}{q} \int_{r_0}^{\infty} \frac{(1+\alpha r)}{r^2} e^{-\alpha r} \sin qr\, dr,$$

where $\mathbf{q} = \mathbf{k}' - \mathbf{k}$. The integrals in the expression for $J(E_p, \vartheta)$ are not in explicit form. They must be calculated for given values of the energy of the incident proton E_p and for the scattering angle ϑ. In Eq. (3) we have used the notation

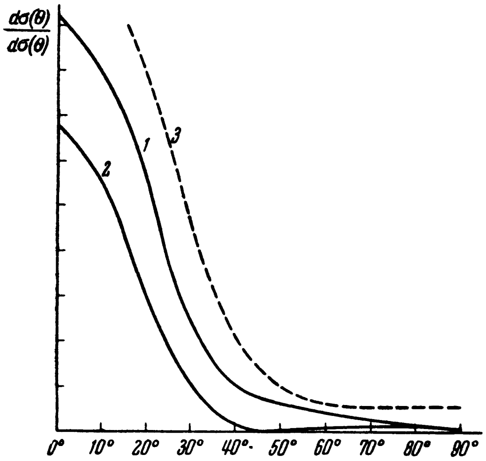
$$\alpha = \hbar^{-1}\sqrt{2\mu\varepsilon}, \quad \beta = \hbar^{-1}\sqrt{2\mu(V_0 - \varepsilon)}, \quad \gamma = \varkappa + \alpha_1,$$

where μ is the effective neutron mass with relation to the Be^8 core in the Be^9 nucleus, $\epsilon = 1.66$ mev is the binding energy of the neutron in the Be^9 nucleus, V_0 is the depth of the square potential well in the interaction between the unpaired neutron and the nuclear core, and r_0 is the width of this well. As has been shown in Refs. 1 and 2, $r_0 = 5 \times 10^{-13}$ cm and $V_0 = 12$ mev. Q is the energy liberated in the reaction and a is obtained from

$$\frac{a^2}{2}\left\{\beta r_0 + \left[(2+\alpha r_0)\frac{\beta^4}{\alpha^4} + (1+\alpha r_0)\frac{\beta^2}{\alpha^2} - 1\right]\frac{\sin^2\beta r_0}{\beta r_0}\right\} = 1. \qquad (4)$$

Experimental curves are given in Ref. 3 for the angular distribution of deuterons from the $Be^9(pd)$ Be^8 reaction at proton energies of 5, 6, 7, 8 and 22 mev.

We have calculated the angular distribution from Eq. (3) at 5-8 mev. In the Figure, Curve *1* is the angular distribution at $E_p = 8$ mev. The angular



distributions at 5, 6 and 7 mev do not differ appreciably from the distribution at 8 mev, and the distribution at 5 and 6 mev for angles from 70^0 to 90^0 is in better agreement with the experimental curve than curve *1*. At 5 to 8 mev, the experimental distributions are identical within the limits of experimental error and are represented by curve ?. The reaction could also be calculated by Butler's theory[4], from the reverse reaction $Be^8(dp)Be^9$. The corresponding distribution at E_p = 8 mev is given by curve *2*. From a comparison of curves *1* and *2* with each other on the one hand, and with the experimental curve *3* on the other hand, we can see that curve *1* is in somewhat better agreement with experiment than curve *2* (especially for angles from 35° to 70°), although it does not differ appreciably as a whole from Butler's curve *2*.

It is well known that Butler's approximation is equivalent to a Born approximation in which the interior of the nucleus is neglected. Our result shows that an approximate calculation, which includes the interior of the nucleus, does not essentially change the angular distribution of deuterons in the $Be^9(pd)Be^8$ reaction that is obtained on the basis of Butler's theory.

We mention in conclusion that we have also calculated the angular distribution for a square well (instead of a Yukawa potential) interaction between the proton and the neutron of the nucleus. The result is practically the same as the distribution obtained from Eq. (3).

I consider it an obligation to express my gratitude to Professor V. I. Mamasakhlisov for his interest and for a number of suggestions.

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Polarization of Elastically Scattered Deuterons

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It is known that the scattering of polarized particles provides important information regarding the spin dependence of their interactions. High energy polarized particles can be obtained by scattering on nuclei. The polarization is due to the spin-orbit interaction. A number of papers have presented calculations of the polarization of particles with spin 1/2. Lepore[1] has given a calculation of the scattering of polarized nucleons by nuclei with zero spin. The present note is concerned with the elastic scattering of polarized deuterons by nuclei with zero spin. This problem is similar to the problem of triplet nucleon-nucleon scattering[2].

The polarization of a deuteron beam is characterized by the three components of the spin vector and the five components of the symmetric second rank spin tensor with zero trace. Before collision the deuteron is described by the distorted plane wave

$$\Psi_0 = \exp\left[i\left(\mathbf{K}_0\mathbf{r} - \alpha \ln 2Kr\right)\right]\chi_0, \quad (1)$$

where χ_0 is the initial deuteron spin function. Polarization of the ingoing deuteron beam is characterized by the following quantities:

$$\mathbf{P}_{in} = (\chi_0 \mathbf{S} \chi_0^+), \qquad \langle T_{ik}\rangle_{in} = (\chi_0 T_{ik} \chi_0^+), \quad (2)$$

where T_{ik} is a symmetric spin tensor with zero trace:

$$T_{ik} = \tfrac{1}{2}(S_i S_k + S_k S_i) - \tfrac{2}{3}\delta_{ik}.$$

the constant $\alpha = Ze^2\mu/K\hbar$.

For the purpose of obtaining the scattered amplitude the wave function of the system must be expanded in a series of eigenfunctions of the operators