Angular Distribution of Deuterons from \(^9\)Be\( (p, d) \)\(^8\)Be.

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In the last years Butler's theory of stripping is used successfully in nuclear spectroscopy. Recently the reversed-pickup process was investigated \(^1\),\(^5\) with use of the reciprocity theorem. On applying Born's approximation in the present paper we obtain the differential cross-section for the \(^9\)Be\( (p, d) \)\(^8\)Be reaction. This method was used for the stripping by Bathia et al. \(^6\). For the \(^9\)Be nucleus we take the two body (nuclear shell) model. In the calculation we neglect the neutron-\(^9\)Be interaction compared with the neutron-incident proton interaction. We do so, because the n-p interaction is responsible for the process investigated and because in our case this interaction is larger than the n-\(^8\)Be one \(^*\). The p-\(^8\)Be interaction is neglected and particularly the Coulomb effect is not taken into consideration.

The differential cross-section in the center of mass system under our assumption is given by \(^7\):

\[
\frac{d\sigma}{d\Omega} = \left(\frac{1}{2\pi\hbar^2}\right)^2 M_d^* M_p^* (k_d/k_p) (1/8) \sum_{m_d m_p} \int d\xi d\eta d\sigma d\sigma \chi^*_d(\xi) \chi^*_p(\eta) \exp \left[-i k_d r_d + i k_p r_p\right] \chi_\eta(\sigma) \exp [ik_p r_p] \chi^*_\eta(\sigma) |z_d(\sigma) z_p(\sigma)|
\]

where \(M_d^* \), \(M_p^* \) are respectively the proton and deuteron reduced mass; \(\hbar k_p \), \(\hbar k_d \) are respectively the proton and deuteron momenta (in the c.m. system); \(\chi_d \), \(\chi_p \), \(\chi_\eta \), \(\chi^*_\eta \) are respectively the deuteron, \(^9\)Be, proton and \(^8\)Be internal wave functions; \(\rho \) is vector from neutron to proton, \(r_n \) vector from \(^8\)Be to neutron, \(r_p \) vector from \(^9\)Be to proton; \(\sigma_n \), \(\sigma_p \) are respectively neutron and proton spin coordinates, \(\xi \) internal \(^9\)Be coordinates; \(m_i \), \(\mu_p \), \(\mu_d \) are respectively \(^9\)Be, proton and deuteron magnetic numbers; \(V_d \) is the deuteron potential.

\(^*\) Thus we neglect the interaction, which plays the most important role in the reciprocity theorem method.

For spinless particles and rigid center of force one can obtain the analogue of Eq. (1) from the equation (18) given by E. Clementel: Nuovo Cimento, \textbf{11}, 412 (1954).
For the n-*Be interaction we take the spherical well of depth $V_0 = 12.09$ MeV and radius $r_0 = 5 \cdot 10^{-13}$ cm. Then we have $\chi_t = \chi_t(\xi)\Phi_\eta(\theta_\eta\phi_\phi\sigma_\sigma)R(r_\eta); \Phi_\eta R$ is the wave function for the $P_3$ state given e.g. by UBERALL (s). For $V_d$ we take the well of depth $U_0 = -21$ MeV and radius $a = 2.82 \cdot 10^{-13}$ cm. Then $\chi_d$ is the $S$- ground state wave function for the above $V_d (\chi_d = S_{\mu\mu}(\sigma_\sigma\sigma_\sigma)\psi(\phi))$.

On inserting these functions into (1) and taking in the expansion of $\exp[-i\hbar r_n]$ in a series of spherical waves the only term to give the non-vanishing contribution to the integral (with $l=1$) and on performing all the integrations and summations we finally obtain:

$$
\frac{d\sigma}{d\Omega} = \frac{1}{2\pi\hbar^2}M^* M^*_d(k_d/k_p)3\pi G(K)^2 I_1(k)^2.
$$

(2)

$$
G(K) = \frac{4\pi K}{K} \int_0^\infty dq \cdot q V_d(q)\psi(q) \sin Kq = 
(2\pi A U_0/K) \{\sin (\alpha + K)a/(\alpha + K) - \sin (\alpha - K)a/(\alpha - K)\},
$$

where $A = \sqrt{2/2\pi(1 + \alpha)}, \alpha = \sqrt{M(U_0 - \varepsilon_\alpha)/\hbar} (\alpha = \sqrt{M\varepsilon_\alpha/\hbar}, \varepsilon_\alpha =$ deuteron binding energy, $M =$ nucleon mass).

(3)

$$
I_1(k) = \sqrt{\pi/2} \int_0^\infty dr_n r_n^2 R(r_n)J_3(kr_n)/\sqrt{kr_n},
$$

appears identical with the integral calculated by UBERALL (*) (Eq. (13)) in the theory of the photoeffect of *Be at large energies. $K$ and $k$ are respectively given by:

(5)

$$
K^2 = \frac{1}{4} k_d^2 + k_p^2 - k_d k_p \cos \theta_s, \quad k^2 = \frac{64}{81} k_p^2 - \frac{16}{9} k_d k_p \cos \theta_s,
$$

where $\theta_s$ is the scattering angle in the c.m. system.

Fig. 1 represents the relative values of the differential cross-section in the laboratory frame $(d\sigma_L/d\Omega_L)$ compared with the experimental data given by COHEN (3) (22 MeV protons) and HARVEY (1) (8, 7, 6, 5 MeV, average 6.5 MeV). The theoretical angular distribution for 22 MeV protons sinks to zero value for large angles faster than the experimental angular distribution (this is a common feature of stripping reactions). Unfortunately there are no experimental data for small angles for 22 MeV. The uncertain present data for 5-8 MeV protons give no possibility of precise comparison of our results with experiment.

The absolute values of $d\sigma_L/d\Omega_L$ for the angles $\theta_L$: 0° and 20° resulting from (2) are respectively for 22 MeV protons: 1.4, 0.5 barn/steradian and for 6.5 MeV protons: 2.6, 2.0 barn/steradian. The absolute value of $d\sigma_L/d\Omega_L$ resulting from Harvey’s experiments seems to be about 0.024 barn/steradian. However this discrepancy