EFFECT OF COULOMB AND NUCLEAR INTERACTIONS ON DEUTERON STRIPPING REACTIONS

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The differential cross section for the $Si^{30}(d, p)Si^{31}$ reaction is calculated taking into account Coulomb and nuclear interactions. Including these interactions has little effect on the ratio of the cross sections at the maxima of the angular distributions for different states of the final nucleus ($l = 0$ and $l = 2$).

It is known that the absolute value of the cross section for a stripping reaction of the type (d, p) and (d, n) is much more sensitive to the Coulomb and nuclear interactions of the particles participating in the reaction than are their angular distributions. To study the influence of these interactions we have computed the differential cross section for stripping with distorted deuteron and proton waves, for the reaction $Si^{30}(d, p)Si^{31}$ which was investigated in [1]. The interactions in the initial and final states were accounted for using the formula found in the paper of Tobocman and Kalos.[2] The values of the radial Coulomb functions were taken from tables computed on the "Strela" digital computer of Moscow State University.[3]

The computation was carried out for the $Si^{30}(d, p)Si^{31}$ reaction with formation of the final nucleus in the ground state ($l_n = 2$, Q = 4.36 Mev) and the first excited state ($l_n = 0$, Q = 3.61 Mev) for deuterons with an energy of 4.25 Mev. The radial integrals entering into the computational formulas were found by numerical integration. The maximum values of the orbital angular momenta of the deuteron and proton were taken to be 6 and 8, respectively. The integration was carried out to the value kr = 8 (where k is the wave number of the captured neutron). The errors due to the neglect of higher orbital angular momenta and large values of kr did not exceed a few percent.

The computed angular distributions are shown in the figure for three cases: 1) Coulomb and nuclear interaction not included; the angular distribution coincides with Butler's results ($R = 6.5 \times 10^{-13}$ cm); 2) only the Coulomb interaction is included; 3) includes the Coulomb interaction plus the nuclear scattering of the protons by a hard sphere of radius 5.5×10^{-13} cm and scattering of the deuterons by a hard sphere of radius 6.5×10^{-13} cm.

As expected, for the case of $l = 2$, including the Coulomb interaction shifts the principal maximum, which was at 45° for the Born approximation, toward larger angles. This shift is about 15°. Putting in the nuclear interaction gives a shift of the maximum in the opposite direction by 20°. Just as in the work of Tobocman and Kalos,[2] the characteristic features of the computed distributions are: a) only a slight difference from the Butler theory at small angles and b) nonzero cross section at the minima.

Inclusion of Coulomb and nuclear corrections results in a considerable reduction in the absolute cross section for the reaction. Although the computations of the absolute cross section are qualitative, they nevertheless give much more reliable values for the cross sections than do the plane-wave computations of the Butler theory. For easy visualization, the differential cross sections for all three variants of the interaction are shown on the figure with the same value at the principal maximum; their actual relative amplitudes are given by the normalization factor N, using the relation

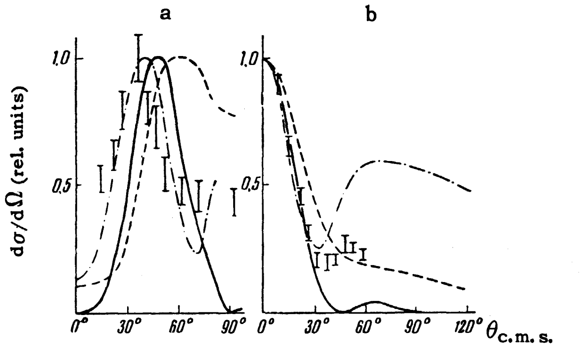
$$\sigma(\vartheta) = N\sigma_0(\vartheta), \quad (1)$$

where $\sigma_0/(\theta)$ is the differential cross section computed from the Butler theory. The computed values of N are presented in the table, in which we also give the results of Tobocman and Kalos [2] for the $F^{19}(d, p)F^{20}$ reaction with formation of the final nucleus in the ground ($l = 2$, Q = 4.37 Mev) and excited ($l = 0$, Q = 0.88 Mev) states.

The main conclusion from the results given in the table is that when one includes Coulomb

Reaction	E_d, Mev (lab)	E_d/B (cms)	$l=0$ N_c	$N_{c+n.s.}$	$N_{c+n.a.}$	$l=2$ N_c	$N_{c+n.s.}$	$N_{c+n.a.}$
$F^{19}(d,p)F^{20}$	14.3	5.3	0.74	0.16	0.38	0.47	0.21	0.23
$F^{19}(d,p)F^{20}$	3.6	1.3	0.16	0.13	0.08	0.20	0.07	0.15
$Si^{30}(d,p)Si^{31}$	4.25	1.1	0.27	0.008	—	0.03	0.004	—

N_c is the correction for Coulomb interaction, $N_{c+n.}$ the correction for Coulomb and nuclear interaction; n.s. denotes hard-sphere scattering of protons for the fluorine reaction and hard-sphere scattering of protons and deuterons for the silicon interaction; n.a. means absorption of protons with $l \leqslant l_1$, where $l_1 = \hbar^{-1} r[2m_p(E_d + Q - Ze^2/r)]^{1/2}$; E_d is the deuteron energy and B is the height of the Coulomb barrier.



Angular distribution of protons, computed for three interaction variants, for the reaction Si^{30} (d, p) Si^{31} with formation of the Si^{31} nucleus a) in the ground state, $l = 2$; b) in the first excited state (0.76 Mev), $l = 0$. The experimental points are from data of[1], the solid line is the Butler theory; the dashed line includes Coulomb interaction; the dot-dashed curve includes both Coulomb and nuclear interactions.

and nuclear interactions the ratio of the corrections $N_{l=0} / N_{l=2}$ for formation of the final nucleus in different states is relatively close to unity and varies from 0.5 to 2, depending on the value of the parameter E_d/B and the character of the nuclear interaction which is included.

The fact that the ratio of the corrections for different values of the orbital angular momentum transfer l is close to unity is important, since it allows us in analyzing the structure of different states of the final nucleus to use the reduced widths computed from the Butler theory.

Because of the incompleteness of the theory, the absolute values of the corrections N and, consequently, the absolute values of the reduced widths are correct only to order of magnitude. One can give a convenient criterion for the applicability of such corrections to the stripping cross section. Since the value of the dimensionless reduced width θ^2 in stripping reactions must not exceed unity, the value of θ^2 computed including the corrections must satisfy the relation

$$\theta^2 = \theta_0^2/N \leqslant 1, \quad (2)$$

where θ_0^2 is the dimensionless reduced width computed from the simple Butler theory. Then we must satisfy the condition

$$N \geqslant \theta_0^2. \quad (3)$$

This simple criterion shows that the correction N for Coulomb and nuclear interaction which appears in the relation (1) must not be less than the dimensionless reduced width θ_0^2 computed from the Butler theory omitting the perturbing interactions.

[1] V. G. Sukharevskii, JETP **36**, 52 (1959), Soviet Phys. JETP **9**, 37 (1959).

[2] W. Tobocman and M. H. Kalos, Phys. Rev. **97**, 132 (1955).

[3] Luk'yanov, Teplov and Akimova. Tablitsy kulonovskikh volnovykh funktsii (Tables of Coulomb Wave Functions) Computer Center, AN SSSR, 1961.

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314