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Deuteron stripping on nuclei at intermediate energies

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Abstract

A general analytical expression for the double differential cross section of deuteron stripping reaction on nuclei at intermediate energies of incident particles was obtained in the diffraction approximation. Nucleon–nucleus phases were calculated in the framework of Glauber formalism and making use of the double-folding potential. The exact wave function of deuteron with correct asymptotics at short and long distances between nucleons was used. The calculated angular dependencies of cross sections are in good agreement with corresponding experimental data.

Keywords: Deuteron stripping; Double-folding potential; Intermediate energies

1. Introduction

The binding energy of deuteron is low. Therefore, when the latter collides with nuclei, inelastic processes are the most probable ones: the deuteron breakup in the nuclear Coulomb field (mainly at low deuteron energies) and the deuteron stripping, when one of deuteron's nucleons is absorbed by the target whereas the other is released as a reaction product. In the intermediate energy interval, the stripping reaction is mainly a result of direct interaction (the capture of deuteron's nucleon by the nucleus), and the differential cross section of reaction is characterized by a sharp peak at particle emission angles $\Theta \ll 1$. The analysis of the angular and energy distributions of cross sections in the deuteron stripping reaction allows additional information on

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the residual nucleus structure and reaction mechanisms to be obtained, being one of the most important sources of spectroscopic data in nuclear physics.

For the first time the theory of deuteron stripping at intermediate energies was proposed by R. Serber [1] for transparent and opaque target nuclei, making no allowance for the diffuseness of their surface. Later, the formalism of inclusive deuteron stripping reaction on nuclei was developed by Akhiezer and Sitenko in the work [2] on the basis of diffraction nuclear model [3,4], and its various aspects were afterwards analyzed and improved by other authors (see [5,6] and the references therein).

The general formula for the inclusive deuteron stripping cross section [2] is inconvenient for the analysis and direct numerical calculations, because it contains a fivefold integral. Therefore, it is usually modified for practical purposes by introducing additional conditions and restrictions (e.g., the nucleus is opaque and non-diffuse; the deuteron radius is much smaller than the target one; and so on). However, this integral can be transformed into a general analytical expression if Gaussian-like functions are used as integrands. Gaussoid functions can be used here as basis ones for the expansion of both the deuteron wave function (the variational problem) and the profile functions of arbitrary forms. Notice that a similar technique is widely applied in the variational approach to describe bound states [7], to parametrize the charge densities in the ground state of nuclei [8,9], and in scattering problems [10], which makes possible to calculate the corresponding scattering phases and form factors analytically.

2. Formalism

Light and medium nuclei were selected as targets, because in this case and in the case of intermediate energies, the Coulomb interaction can be neglected. The spins of the deuteron's nucleons and the target were also not taken into account.

The general formula for the differential cross section of deuteron stripping is derived as follows [2]. Let a proton be a particle captured by the target nucleus at stripping. The wave function of the neutron released in this reaction will be presented as a plane wave: $\psi(\mathbf{r}_1) = \exp(i\mathbf{k}_1\mathbf{r}_1)$, where $\mathbf{k}_1$ is the neutron momentum, and $\mathbf{r}_1$ its radius vector. The wave functions of the proton absorbed by the nucleus are coefficients of the integral expansion of deuteron wave function near the nucleus in series of functions $\psi(\mathbf{r}_1)$. In other words, the probability amplitude that the neutron has the momentum $\mathbf{k}_1$ and the proton is at the point $\mathbf{r}_2$ equals

$$a(\mathbf{k}_1, \mathbf{r}_2) = \int d^{(3)}\mathbf{r}_1 \exp(-i\mathbf{k}_1\mathbf{r}_1) S_1 S_2 \varphi_0(\mathbf{r}) \psi_0(\mathbf{r}_d), \tag{1}$$

where $S_i = 1 - \omega_i$ are the neutron ($i = 1$) and proton ($i = 2$) diffraction multipliers, ω_i are the nucleon–nucleus profile functions, and $\varphi_0(\mathbf{r})$ and $\psi_0(\mathbf{r}_d)$ the wave functions of deuteron and its center-of-mass motion, respectively. Let the deuteron move in the positive direction of axis $0Z$. Then, the proton concentration in the plane $Z = 0$ is determined by the squared absolute value of amplitude (1),

$$\left|a(\mathbf{k}_1, \mathbf{s}_2)\right|^2 = \left|S_2 \int d^{(3)}\mathbf{r}_1 \exp(-i\mathbf{k}_1\mathbf{r}_1) S_1 \varphi_0(\mathbf{r})\right|^2, \tag{2}$$

where $\mathbf{s}_2$ is the impact parameter vector of proton.

Now, integrating the difference between formula (2) taken at $S_2 = 1$ and $S_2 \neq 1$, i.e. when the target does not absorb and absorb protons, respectively, over the whole impact plane, we obtain the sought expression for the double-differential (with respect to the neutron emission angle and energy) cross section,