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Knocking out of neutron by the proton from nucleus

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Abstract

The study of the cross sections of the knocking out nucleons provides important information about the asymptotic behaviour of the scattering amplitude. During the interaction of the incident particle with nucleus, its function is distorted. In this case, we are talking about those components of the wave function for which the probability of interaction with the target is small, i.e. during the collision, only a small part of the target is excited (an elastic collision with only one of its constituent particles). To do this, it is necessary to use the "point" component of the wave function of the incident particle.

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1. Introduction

The study of the cross sections of the knocking out nucleons provides important information about the asymptotic behaviour of the scattering amplitude. During the interaction of the incident particle with nucleus, its function is distorted. In this case, we are talking about those components of the wave function for which the probability of interaction with the target is small, i.e. during the collision, only a small part of the target is excited (an elastic collision with only one of its constituent particles). To do this, it is necessary to use the "point" component of the wave function of the incident proton.

In this paper, we consider processes knocking out of neutron by the proton in

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the eikonal approximation with distorted waves. The high-energy or eikonal approximation is broad and consistent for describing scattering in complex groups, like scattering in some optical continuum. In this approximation, after the closure of the power, there is a closure of the projection of the k-direction momentum: pk = const. This means that the movement in the transverse directions is completely neglected. In addition, in this approximation, restrictions on any masses and coordinates of particles are not collected, while both the final radius and the recoil are calculated exactly. Therefore, the high-energy approximation can be used for angular distributions of scattered particles.

2. Scattering matrix equation

The eikonal approximation is often used to describe the scattering of particles by nuclei. This approximation is applicable if the energy of the incident nucleon is much greater than the binding energy of individual nucleons in the nucleus. To simplify the many-particle problem, it is assumed that the incident nucleon interacts with only one nucleon of the nucleus at a time. In this case, the collision can be regarded as a short impact, during which the forces binding the impacted nucleon to the nucleus play no role. Thus, during the time of interaction, the impacted nucleon can be considered "free", and the binding forces in the nucleus determine only the momentum distribution function of nucleons. In the eikonal approximation, the cross section of any process of interaction of a nucleon with a nucleus is expressed in terms of the amplitude of the scattering of a nucleon by an individual nucleon. It is also assumed that the scattering of a nucleon by any nucleon of the target nucleus is not affected by the presence of other nucleons in the nucleus.

Consider the scattering of a proton p on the nucleus A and the final state, the proton and neutron are emitted. Final nucleus $B = A - 1$. The potentials are local, short-range and weakly singular: $r^2V(r) \to 0$ at $r \to 0$.

We make the widely used assumption that the exchange of nucleons between two nuclei is not taken into account and that the target nucleons are not excited.

We will use the zero-radius approximation [1]. In this approximation, the neutron is emitted at the same point where it interacts with the proton. The need to introduce a finite interaction radius for calculating exchange processes is more or less acceptable for calculating direct processes in reactions with the transfer of one particle.

We choose the wave function of the initial system in the form:

$$\Psi_i = e^{k_p r_p}\psi\left(J_i M_{J_i} T_i M_{T_i}\right), \tag{1}$$

where $k_p = p_p/\hbar$ is the wave number of the proton, and $\psi(J_i M_{J_i} T_i M_{T_i})$ is the internal wave function of the target nucleus with total momentum $J_i$and isospin T_i.

For the wave function of the final state, we have

$$\Psi_f = e^{ik'_p r'_p} e^{ik_n r_n} \varphi_B(J_f M_{J_f} T_{T_f}). \quad (2)$$

Here $\varphi_B(J_f M_{J_f} T_{T_f})$ the wave function of the final nucleus A-1.

The wave functions (1) and (2) have the wrong asymptotic at large distances, but a good description of the elastic form factors.

The Schrödinger equation for this system has the form:

$$\left[-\frac{\hbar^2}{2m_p}\Delta_p - \frac{\hbar^2}{2m_n}\Delta_n + V(r_1) + U(r_2)\right]\Psi(r_1 r_2) = E\Psi(r_1 r_2), \quad (3)$$

where $V(r) = -V_0/(1+\exp(r-R_0)/\alpha)$ – Woods-Saxon potential, $U(r) = -V_0 e^{{r_0}^2/r^2}$ – Gaussian potential,

$$E = \frac{p_p^2}{2m_p} + \frac{p_n^2}{2m_n} - \varepsilon_{\text{св}}, \quad (4)$$

and $\varepsilon_{\text{св}}$ – is the binding energy of the neutron in the initial nucleus A.

We will calculate the matrix element of the process using the method of distorted waves [2]. By the method of distorted waves, which takes into account the finite radius of interaction between particles, we mean the following method for calculating the matrix element. When the interactions responsible for the rearrangement of the system from initial to final are taken the same as in the three-body problem, and the interactions of the initial and final particles with the corresponding nuclei are described in the optical model approximation, i.e. in the approximation of the two-body problem. In this case, only elastic scattering by the complex potential is taken into account.

In the distorted wave approximation, the exact wave function is replaced by $\Psi(r_1 r_2)$

$$\Psi(r_1 r_2) \to \frac{1}{(2\pi)^3}\, dKdr\, \varphi_B(r)\psi_n(r_n) \quad (5)$$

In the eikonal approximation with distorted waves, the scattering matrix element has the following form [3]

$$M = \frac{1}{(2\pi)^6}\int e^{i(k_p + k'_p - k_n)r_p} \psi_B^*(r)\, \psi_A(r) \times$$

$$\times \left(k_n|(V(r)+U(r)|k_p\right) dr dk_p dk_n. \quad (6)$$

Knowing the matrix element (6), for the cross section of the process we obtain:

$$\frac{d\sigma}{dp_p dp_n dp_q} = \frac{2\pi}{\hbar}\frac{1}{(2\pi\hbar)^6}\frac{m_p}{q_p}\ \ \delta\left(q_p - q_n - q_B\right)\delta\left(E_i - E_f\right)\sum_{\Lambda'}\beta^2_{if\Lambda\Lambda'}, \quad (7)$$

where

$$\beta_{if\Lambda\Lambda'} = \left\langle A-1, J_f M_{J_F} T_{T_f}; J_n M_n T_n \middle| e^{iq(r_{A-1}-r_n)}; A J_i M_i T_i \right\rangle \quad (8)$$

is a factor determined by the structure of the nucleus. Integral (8) is nonzero only in the case when the law of conservation of the moment of quantity is satisfied, namely, the vector sum of three moments J_f, J_n and Λmust be equal to J_i, where $\Lambda$is the moment of momentum carried away by the neutron. The main feature of the integrals appearing in expressions (8) is that the interaction potentials and wave function of the relative movement and distorted waves also depend on the relative different combinations of variables. Furthermore, they are presented in nucleon variables. A very important issue is the separation of variables. The possibility of analytical calculation of integrals over angular variables, as well as over those variables that are not related to the interaction of particles, depends on this.

4. Conclusion

Formula (7) determines the general scheme for calculating the differential cross section of the process under consideration. A characteristic feature of the approximation used is the division of its methodological basis into two main parts. The first part refers to the theory of nuclear reactions, since it consists in choosing an approximation for (5) that determines the reaction mechanism. The second part refers to the theory of nuclear structure, which contains information about the spectrum of the final nucleus.

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