SHELL-STRUCTURE INFLUENCE ON THE MULTINUCLEON TRANSFER IN NUCLEON TRANSFER MATRIX ELEMENTS

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The experimental data on the charge (mass) distributions of reaction products with heavy ions [1] and on the yields of light particles at collisions leading to formation of compound nuclei [2] showed that at the formation and evolution of dinuclear system the individual particularities of nuclear shell structure are conserved. The shell structure of the atomic nuclei is observed in the mass and excitation energy distribution of the reaction products in the nucleus-nucleus collision at near barrier energies [3] and at fission of nucleus [4]. The microscopic model should be applied to study these effects. Its composite elements are - realistic schemes of single-particle states, separating energy of nucleons, single-particle matrix elements of damped nucleon transitions in nuclei caused by influence of field of projectile and matrix elements of transitions of nucleons from nuclei to nuclei. One of such kind models was developed and applied to describe and interpret the experimental data [5, 6]. In calculations of matrix elements of nucleon transfer, eigenvalues of the Woods-Saxon potential was used as single-particle energies in the interacted nuclei. But to simplify the calculation authors of above mentioned model used wave functions of the spherical symmetric well in internal part of nuclei [7]. Nevertheless, the results obtained in the framework of this model are in good agreement with experimental data and allow an understanding of excitation energy non-equilibrium distribution between the reaction products. In this talk, we present results which were obtained by using of eigen energies and wave functions of the single-particle states in the Woods-Saxon potential for both of the interacted nuclei. The calculated widths of the charge distributions of the reaction products were compared with the experimental data to estimate whole contribution of the matrix elements under discussion Another physical quantity depending on the relative distance between centers of nuclei, which reflects correctness of calculation of the matrix elements. In Section 1, the method of calculation of matrix elements describing nucleon transfer between nuclei is presented. Comparison of the results of this work with the results obtained in [7] for the matrix elements and dispersion of charge distribution of products of deep inelastic collisions is discussed in Section 2.

CALCULATIONS OF NUCLEON TRANSFER MATRIX ELEMENTS

Let us consider matrix elements of nucleon transfer from projectile to the target, which is influenced by the mean field, from single-particle state characterized by set of quantum numbers $p=(n_p\, j_p\, l_p\, m_p)$ into single-particle state $t=(n_t\, j_t\, l_t\, m_t)$ of the target. The colliding nuclei suggested to be spherical and wave functions were found by solving equations with the Woods-Saxon potential. Since these wave functions describe single-particle states of nuclei better than other wave functions approximated as harmonic oscillator's wave functions or wave functions of potential well, particularly at periphery of nuclei. These wave functions are of the following form:

$$\psi_{nlj}(\mathbf{r}) = R_{n_i}(r)\cdot Y^{\Omega}_{j_i m_i}(\mathbf{r}/r) \tag{1}$$

where $R_n(r) = \dfrac{N_n}{r} H_n(S(r))\cdot \exp(-\dfrac{S(r)^2}{2})$, $S(r) = \begin{cases} b_1 \cdot \ln(\frac{r}{a}) & r \le a \\ b \cdot \ln(\frac{r}{a}) & r > a \end{cases}$

and, $Y^{l_i 1/2}_{j_i m_i}(\mathbf{r}/r)$ - is the spherical function. The coefficients N_n, b, b_1, a, and energies of single-particle states are found by numerical solving of the Schrödinger's equation with a Woods-Saxon potential [8].

In the coordinate presentation the matrix elements of nucleon transfer has the following form:

$$g_{PT}(\mathbf{R}) = \int_{\infty} d^3\mathbf{r} \cdot \Psi_T^*(\mathbf{r}) \left[\frac{1}{2} \{U_T(\mathbf{r}) + U_P(\mathbf{r}-\mathbf{R})\} \right] \Psi_P(\mathbf{r}-\mathbf{R}) \tag{2}$$

where $\{U_T(\mathbf{r}) + U_P(\mathbf{r}-\mathbf{R})\}$- is a total single-particle potential of dinuclear system (DNS), R - is a distance between centers of DNS nuclei. Using Fourier images of wave functions

$$\psi_{nlj}(\mathbf{p}) = \varphi_{n_i}(p) \cdot Y^{l_i 1/2}_{j_i m_i}(\mathbf{p}/p) \tag{3}$$

and approximation correlation $$\left(-\frac{\hbar^2}{2m}\Delta + U_{P(T)}(\mathbf{r}) \right) \Psi_{P(T)}(\mathbf{r}) = \varepsilon_{P(T)} \Psi_{P(T)}(\mathbf{r}) \tag{4}$$

we can get the following expression for matrix element of nucleon transfer.

$$g_{PT}(R) = \frac{1}{(2\pi)^3} \int_{\infty} d^3\mathbf{p} \cdot e^{i\mathbf{pR}} \varphi_T^*(p) \left[\frac{1}{2} \left(\left\{ \varepsilon_P - \frac{\hbar^2}{2m} p^2 \right\} + \left\{ \varepsilon_T - \frac{\hbar^2}{2m} p^2 \right\} \right) \right] \varphi_P(p) \tag{5}$$

After integrating (5) over angular variables we get

$$\begin{aligned} g_{PT}(R) = {} & \frac{(-1)^{m_T - \frac{1}{2}}}{16\pi^3} \left[(2j_P+1)(2j_T+1)\right]^{1/2} \sum_L i^L (j_T - \tfrac{1}{2}, j_P \tfrac{1}{2} | L0) \cdot (j_T - m_T, j_P m_P | L0) \times \\ & \times \int_0^{\infty} dp \cdot p^2 j_L(pR) \left[\left\{ \varepsilon_P - \frac{\hbar^2}{2m} p^2 \right\} + \left\{ \varepsilon_T - \frac{\hbar^2}{2m} p^2 \right\} \right] \varphi_{l_T}^*(p) \varphi_{l_P}(p) \end{aligned} \tag{6}$$

The integral (6) can not be integrated analytically because of complexity of wave functions (1) and results of numerical calculations of (6) are presented in Section 2.

RESULTS OF CALCULATIONS AND THEIR ANALYZES

Matrix elements of the transition of nucleon from the state $1f_{7/2}$ of projectile-nucleus and on the state $1p_{3/2}$ of target-nucleus calculated by the Esq. (6) and corresponding equation of Ref. [7] are compared in Fig. 1. The matrix element calculated by realistic wave functions of the spherical Woods-Saxon potential (solid line) has not depression at the relative distance corresponding to the sum of radii of half nucleon density in nuclei. The depression of the matrix elements calculated according to method of Ref. [7] is caused by join of solutions of the Schrödinger equation in internal and external parts of nucleus for the spherical well. The difference in some factors between absolute values of g_{PT} calculated by the two methods under discussion is explained by the fact that different wave functions were used.

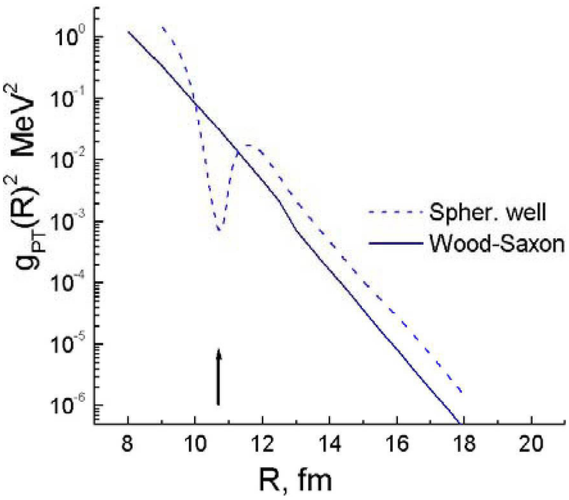

Fig. 1. Comparison of matrix elements calculated as a function of distance between nuclear centers by the wave functions of spherical well and the Wood-Saxon potential.

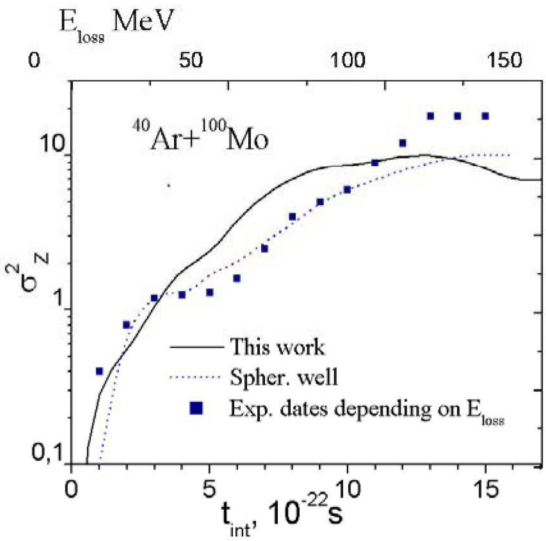

Fig. 2. Dependence of dispersion of the measured and calculated charge distributions of the reaction products in deep-inelastic collision on the interaction time.

As one can see from Fig. 2, our result obtained for the dependence of dispersion of the charge distribution of reaction products in $^{40}Ar + ^{100}Mo$ on interaction time are in good agreement with the corresponding experimental data. The experimental interaction time is estimated from the angular distribution of the reaction products.

CONCLUSIONS

We estimate correctness of the approximation of the mean-field of nuclei interacting at low energy heavy ion collisions by the spherical well which is widely used in the model based on dinuclear concept due to its simplicity. It was performed by comparison of the calculated matrix elements for the nucleon transfer between single-particle states of the projectile and target nuclei at deep-inelastic collisions of heavy ions by using the wave functions obtained by the numerical solution of the Schrödinger equation for the Woods-Saxon potential. The absolute values of the matrix elements calculated as a function of the relative distance between nuclei centers by the latter method occurred to be several times lower those that obtained by wave functions of spherical well. The depression inherent to the matrix elements at the value of the relative distance corresponding to the sum of radii of the interacting nuclei is not observed in case of calculations with the wave functions of the Woods-Saxon potential. This is an expected result. Used matrix elements for calculation of dispersion of the reaction products charge distribution at deep-inelastic heavy ions collisions by the both methods under discussion allowed us to reach a good agreement with the experimental data.

We conclude that the approximation by spherical well of the mean-fields of interacting nuclei in the dinuclear system concept is acceptable in spite of its simplicity.

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