TIME-DEPENDENT QUANTUM DESCRIPTION OF NUCLEONS TRANSFERS IN REACTIONS WITH DEFORMED NUCLEI

V.V. SAMARIN

Joint Institute for Nuclear Research, Dubna, Moscow region, Russia

K.V. SAMARIN

Chuvash State University, Cheboksary, Russia

Time-dependent Schrödinger equation for external neutrons of deformed nucleus ^{238}U is numerically solved by difference method for collisions ^{40,48}Ca+^{238}U with energies in vicinity to a Coulomb barrier. The spin-orbital interaction were taken into consideration during the solution. The probabilities of transfer of neutrons are determined as function on minimum internuclear distances and quantum numbers of initial neutrons states.

1. Introduction

In the theoretical description of the neutron transfers upon heavy atomic nuclei collisions, a few semiclassical models are used [1-5]. They combine classical equations of atomic nuclei motion that are justified by smallness of a de Broglie nuclear wave length and the quantum description of internal one-particle and collective degrees of freedom. The processes of external (valence) neutron transfers at reactions with spherical nuclei were investigated using the time dependent Schrödinger equation with an approximate model in which the spin–orbit interaction was replaced by an effective correction of the Woods–Saxon potential [2] and with exact spin–orbit interaction operator [3]. In this study, the spin–orbit interaction is taken into account in considering frontal collisions of spherical nuclei ^{40,48}Ca with deformed nucleus ^{238}U.

2. Numerical methods and results

In this study the axially symmetric deformed Woods–Saxon potential

$$V(\vec{r},\beta_2,\beta_4) = -V_0\left[1+\exp\left(\frac{r-R(\theta,\beta_2,\beta_4)}{a}\right)\right]^{-1}, \qquad (1)$$

was used for ensuring of an exact asymptotic values of neutrons wave functions out-of-nucleus ^{238}U. At the present time, most of the deformed nuclei shell structure calculations based on Nilsson-Strutinsky method with expansion in harmonic-oscillator wave functions (see, for example, [4,5]). We used alternative method offered in works [6] and based on a numerical solution of Schrödinger's equations at cylindrical coordinates with expansion in Bessel functions. The numerical method of time-dependent Schrödinger equation solution [3] for spinor wave function

$$\frac{d}{dt}\begin{pmatrix}\psi_1\\ \psi_2\end{pmatrix} = \left\{-\frac{\hbar^2}{2m}\Delta + V(\vec{r},t) - b\vec{\sigma}\left[(\nabla V)\vec{p}\right]\right\}\begin{pmatrix}\psi_1\\ \psi_2\end{pmatrix}, \qquad (2)$$

is similarly to split-operator fast Fourier transform (FFT) method without spin-orbital interaction [7].

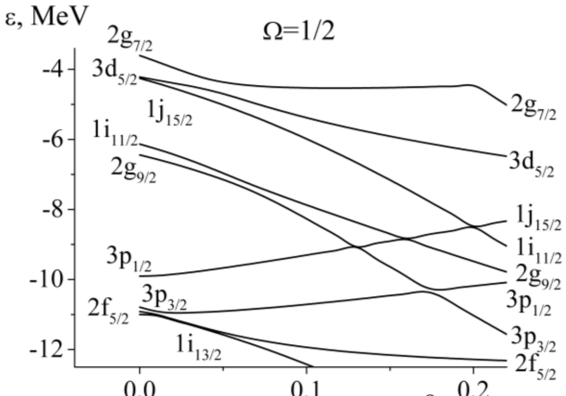


Fig. 1.a) Some upper energy levels for neutron states with module of total angular moment projection to symmetry axis Ω at hypothetic nuclei ^{238}U with quadrupole deformation $0 \le \beta_2 \le 0.2$ and octupole deformation $\beta_4=\beta_2/2$

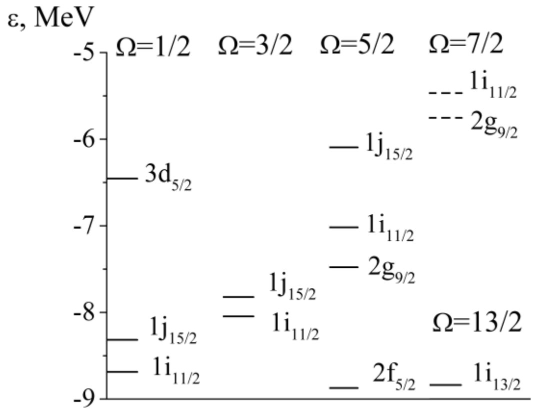


Fig. 2.b) Some upper energy levels for neutron states with module of total angular moment projection to symmetry axis Ω at real nucleus ^{238}U [7] with $\beta_2 = 0.215$ and $\beta_4 = 0.095$, dashed lines correspond unoccupied levels

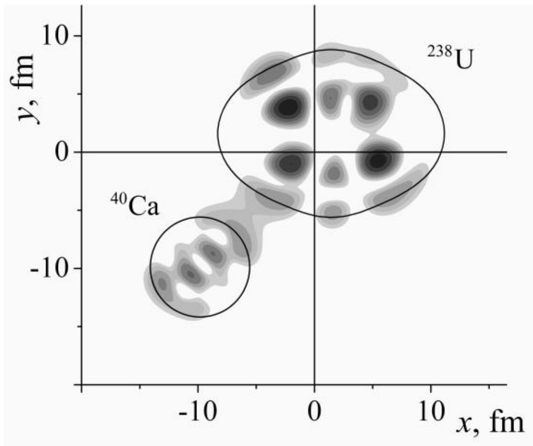
Some upper energy levels for neutron states with module of total angular moment projection to symmetry axis Ω at hypothetic nuclei ^{238}U with quadrupole deformation $0 \le \beta_2 \le 0.2$ and octupole deformation $\beta_4 = \beta_2/2$ and at real nucleus ^{238}U with $\beta_2 = 0.215$ and $\beta_4 = 0.095$ [5] are shown on Fig.1.

Probability densities

$$\rho = |\psi_1|^2 + |\psi_2|^2 , \tag{3}$$

of external neutron of ^{238}U for initial state $1j_{15/2}$ with $\Omega = 5/2$ (upper occupied level, Fig. 1*b*) during frontal collision with the ^{40}Ca and external neutrons of $1f_{7/2}^{8}$ shell of ^{48}Ca during a frontal collision with the ^{238}U (*b*) at energy in the center of mass system *E*=192 MeV are shown on Fig.2.

(a)



(b)

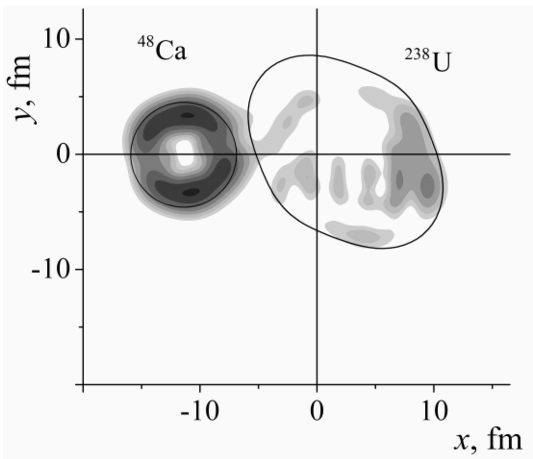


Fig. 2. Probability density $\rho(x, y, z = 0)$ of the external neutron of ^{238}U for initial state $1j_{15/2}$ with $\Omega = 5/2$ during frontal collision with the ^{40}Ca (*a*) and external neutrons of $1f_{7/2}^{8}$ shell of ^{48}Ca during a frontal collision with the ^{238}U (*b*) at energy in the center of mass system *E*=192 MeV. Angle between symmetry axes of deformed nucleus ^{238}U and initial velocity of Ca nuclei equal 45°.

During internuclear distance slowly reducing, potential barrier for neutrons between the potential wells of colliding nuclei goes down. Neutron wave function penetrates into neighbour well mainly along internuclear axis (Fig.2). The probability *p* of neutron transfer after the collisions of nuclei without contact between their surfaces was determined by integrating the probability density (3) over the volume and vicinity of the respective nucleus.

The probabilities of neutron pick-up at reaction $^{40}Ca+^{238}U$ and neutron stripping at reaction $^{48}Ca+^{238}U$ are shown in Fig. 3 as a function of minimum distance *s* between nuclear surfaces for one of possible orientations of deformed nucleus ^{238}U.

(a)

(b)

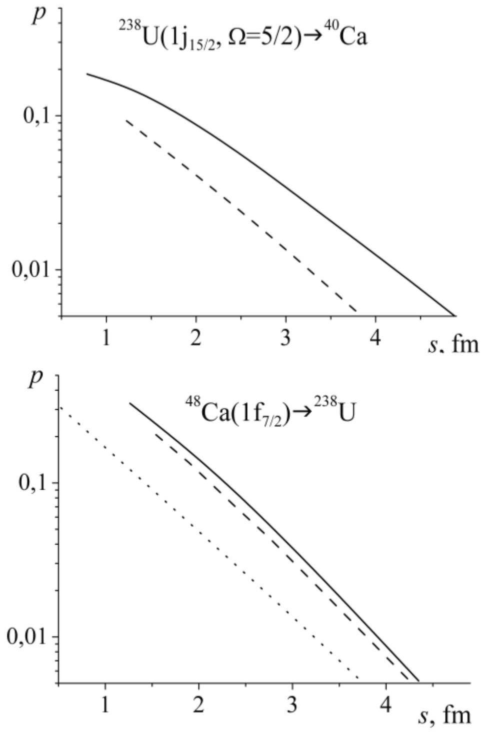


Fig. 3. The probabilities of neutron pick-up at reaction $^{40}Ca+^{238}U$ (*a*) and neutron stripping at reaction $^{48}Ca+^{238}U$ (*b*) as a function of on minimum distance *s* between nuclear surfaces. .Angles between symmetry axes of deformed nucleus ^{238}U and initial velocity of Ca nuclei equal 45°(solid line), 90°(dashed line) and 0° (dotted line).

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