Shell model

The code provides possibility to calculate the single-particle energies and wave-functions (neutron or proton) of deformed nuclear system basing on the Woods-Saxon single-particle potential.

The single-particle energies are found by diagonalize the following Hamiltonian:

$$\hat{H} = \hat{T} + V + V_{\mathrm{LS}} + V_C, \tag{1}$$

where $\hat{T}$ is the kinetic energy operator, V is the Woods-Saxon potential, V_{LS} is the spin-orbit potential, and V_C is the Coulomb potential [1] (for protons only). The Woods-Saxon potential is defined by

$$V(\mathbf{r}) = \frac{V_0}{1 + \exp\left(\frac{r-R}{a}\right)}, \tag{2}$$

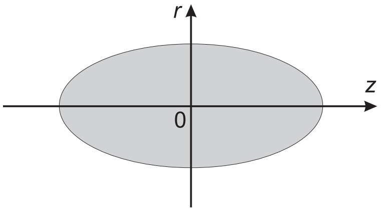
where V_0 and a are the depth and diffuseness of the potential, respectively and $(r - R)$ is a distance between point $\mathbf{r} = \{r, \theta, \varphi\}$ and nuclear surface defined by the function

$$R(\vec{\beta}, \theta) = \tilde{R} \cdot \left(1 + \sum_{\lambda \geq 2} \beta_\lambda \sqrt{\frac{2\lambda + 1}{4\pi}} P_\lambda(\cos\theta)\right), \tag{3}$$

where $\vec{\beta} \equiv \{\beta_\lambda\}$ dimensionless deformation parameters of multiplicity $\lambda = 2$, 3, or 4, P_λ are the Legendre polynomials,

$$\tilde{R} = R_0 \left[1 + \frac{3}{4\pi} \sum_\lambda \beta_\lambda^2 + \frac{1}{4\pi} \sum_{\lambda, \lambda', \lambda''} \sqrt{\frac{(2\lambda' + 1)(2\lambda'' + 1)}{4\pi(2\lambda + 1)}} (\lambda' 0 \lambda'' 0 | \lambda 0)^2 \beta_\lambda \beta_{\lambda'} \beta_{\lambda''}\right]^{-1/3}, \tag{4}$$

$R_0 = r_0 A^{1/3}$ is the radius of the equivalent sphere with the volume of deformed nucleus, and $(\lambda' 0 \lambda'' 0 | \lambda 0)$ are the Clebsch-Gordon coefficients. An example of nuclear shape is shown in Fig. 1.



The spin-orbit coupling field is assumed to be of the form

$$V_{\mathrm{LS}}(\mathbf{r}, \mathbf{p}, \sigma) = -\kappa \frac{\hbar}{(2Mc)^2} \nabla V(\mathbf{r}) \cdot (\mathbf{p} \times \sigma), \tag{5}$$

where κ is the strength constant of the spin-orbit coupling, M is the nucleon mass, $\mathbf{p}$ is the linear-momentum operator, and σ are the Pauli matrices.

The recomended "universal" set [2] of the model parameters are listed in Table .

	V			V_{SO}			
	r_0 (fm)	a (fm)	$V_0 (MeV)$	r_0 (fm)	a (fm)	V_0 (MeV)	κ
neutrons	1.347	0.7	Eq. (6)	1.31	0.7	Eq. (6)	35.0
protons	1.275	0.7	Eq. (6)	1.32	0.7	Eq. (6)	36.0

Table 1: Recomended values of the parameters [2]

$$V_0 = -49.6 \left[1 \pm 0.86 \left(\frac{N - Z}{A}\right)\right], \tag{6}$$

where "+" corresponds to protons and "-" – to neutrons.

[1] J. Damgaard, H.C. Pauli, V.V. Pashkevich, and V.M. Strutinsky, Nucl. Phys. **A135**, 432 (1969).

[2] S. Ćwiok, J. Dudek, W. Nazarewicz, J. Skalski, and T. Werner, Comput. Phys. Commun. **46**, 379 (1987); Z. Patyk and A. Sobiczewski, Nucl. Phys. **A533**, 132 (1991).