MICROSCOPIC DESCRIPTION OF α–PARTICLES INTERACTION WITH ^{7}Li NUCLEI AT LOW ENERGIES

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ABSTRACT:

The experimental data of α-particle elastic scattering on ^{7}Li nuclei are investigated within the framework of optical model by using of phenomenological and microscopical potentials.

For construction of microscopical potentials double folding model and cluster folding model were used. The reproducing of cross-sections increasing on backward angles is achieved by the contribution of heavy stripping mechanism in scattering cross-section.

INTRODUCTION

Scattering of nucleons and compound nuclear particles (deuterons, α-particles, heavy ions) on the nuclei is very important source of information regarding nuclear structure [1]. But parameters of optical potential (OP) of particles interactions with light nuclei at the low and medium energies, received from analyze of differential cross sections of elastic scattering in the frame of optical model (OM) are exposed to uncertainties and require of reliable estimations. The situation is complicated at the scattering of α-particles at the ^{7}Li nuclei. In these cases, cross sections of elastic scattering are formed not only by mechanisms of potential nature, but also by other processes like heavy stripping and exchange process [2], and by effects of coupled channels [3], introducing visible distortions to parameters of optical potential. Besides, the sharp increasing of scattering cross section at the backward angles from energies introduce additional difficulties for determination of potential parameters. For example, cross section of elastic scattering at the E=40MeV backward angles almost for an one order is exceeded its value E= 50MeV[4].

In order to obtain the reliable information regarding a potential of nuclear interactions, received at the cyclotron of INP NNC RK, the experimental data under scattering of α-particles with the energies 40 and 50.5 MeV on the ^{7}Li nuclei are analyzed as in the framework of standard optical model with the potential assignment in the parameterized form and determination of its parameters from comparison of theoretical cross sections with the experimental ones, and in the framework of microscopic model as well, where potentials are based on the effective nucleon-nucleon forces [5]. These constructions are not limited only by using of double-folding procedure, but also include the account of many-particle nucleon-nucleon correlations, modeled by density dependence of effective forces [6], as well as the account of exchange nucleon-nucleon correlations, conditioned by Pauly's principle [6,7].

There are also considered the realization of cluster folding-model, based on the projectile interactions potentials with triton and α-particle in nucleus, which are then averaged on the two-body wave functions, i.e. this procedure takes into account multicluster structure of nucleus. This model was earlier offered in order to calculate the α -particles interaction potentials on the nuclei ^{6}Li [8,9]. In this work similar calculations were performed for scattering on the nucleus ^{7}Li. It was also tried to explain the raise of elastic scattering section on the large angles by introducing the mechanism of heavy stripping [2].

Formalism of the calculations in the framework of double -folding model

Let's consider an interaction of compound projectile with nucleus-target. In the first order under an effective nucleon-nucleon (NN) forces the potential of interactions can be represented in the form of:

$$U(R) = U^{D}(R) + U^{EX}(R) \tag{1}$$

where first component is the direct potential of double-folding model

$$U^{D}(R) = \iint \rho^{(1)}(r_1)\upsilon(s)\rho^{(2)}(r_2)dr_1 dr_2 \qquad s = r_2 - r_1 + R \tag{2}$$

U_{EX}(R) -the exchange potential, the local form of which looks as follows [10]:

$$U^{EX}(R) = \iint \rho^{(1)}(r_1, r_1 + s)\upsilon^{EX}(s)\rho^{(2)}(r_2, r_2 - s)\exp[ik(R)s/\eta]dr_1 dr_2 \tag{3}$$

local impulse is determined by formula:

$$k^2(R) = (2mM/\hbar^2)[E - U(R) - V_C(R)], \qquad \eta = A_1A_2/(A_1+A_2) \tag{4}$$

where υ(s) (υ^{EX} (s)) - is direct (exchange) effective interaction component,

$\rho^{(i)}$(r,r') - density matrix of colliding nuclei and V_C(R) - Coulomb potential.

Let's discuss an enter information, required for potentials calculation. In our further calculations, as effective nucleon-nucleon forces was used the full M3Y-interaction, based on the G-matrix elements of Reid and Elliot interactions [6]. It was earlier showed [7] that at the low energy the account of exchange effects in the explicit form is important, so it is required all (direct and exchange) components of effective forces. For densities of neutrons and protons distributions in the nucleus-targets Fermi distribution with the parameters, determined for protons from electrons scattering on these nuclei, is applied. The geometrical parameters for neutron distributions are taken the same as for proton distribution. Densities are normalized on protons and neutrons number in nuclei, respectively. For α-particle gauss distribution was used. Further the obtained potential is parameterized in the Wood-Saxon form.

Formalism of calculations in the framework of cluster folding model.

Potential of α -particles interactions with nucleus ^{7}Li in cluster folding model represents the integral:

$$V_{\alpha-^7Li}(\vec{R}) = \left\langle \Psi_{^7Li}(\vec{x})\varphi_\alpha \middle| V \middle| \Psi_{^7Li}(\vec{x})\varphi_\alpha \right\rangle \quad (1)$$

where (x,y) the set of Jacobi coordinates, and R- radius-vector, connecting center of mass of α-projectile and nucleus ^{7}Li. In this formula:

$$V = V_3(r_{12}) + V_2(r_{13}) \quad (2)$$

where V_k - the potentials of intercluster interactions between i and j particles, depending from their relative distance r_{ij}, where r_{ij} vectors are connected with the internal coordinates of nuclei (x,y) and vector R by the following way:

$$\begin{cases} \vec{r}_{13} = -\frac{3}{7}\vec{x} - \vec{R} \\ \vec{r}_{12} = +\frac{4}{7}\vec{x} - \vec{R} \end{cases} \quad (3)$$

As wave function of nucleus ^{7}Li was used wave function in α+t- model [11].

The potential of interaction V_{12} is correspond to interaction of α-projectile with triton in the nucleus ^{7}Li. As α-α interactions was chosen the famous potential of Buck form, which used at the calculations of nucleus ^{9}Be as well [12].

$$V = V_0 \exp(-\eta r^2) \quad (4)$$

A required potential of α -particles interactions with the nucleus ^{7}Li is obtained by expression averaging (2) under wave functions of main state of ^{7}Li nucleus. Further an obtained potential is parameterized in the Wood-Saxon form.

The calculated potential in the framework of cluster folding model is showed in Fig.1 with the optical potential (see further in text) and double folding-potential.

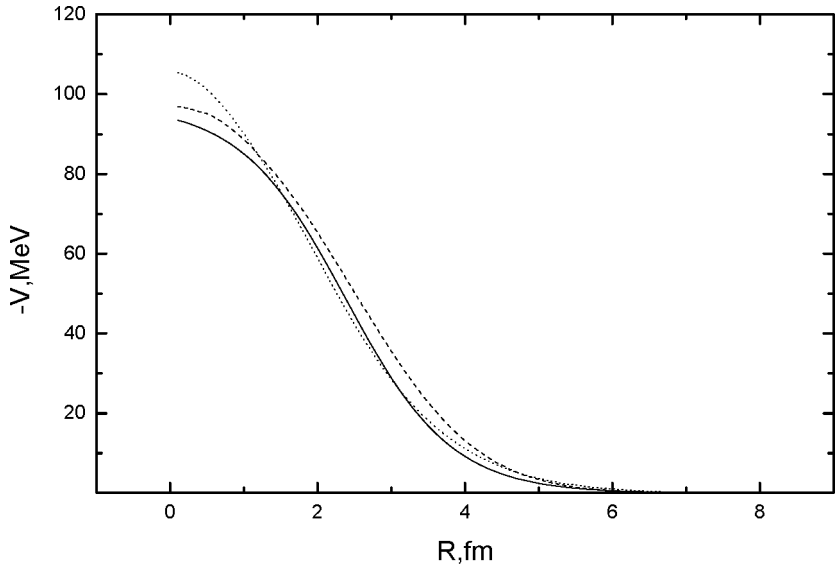


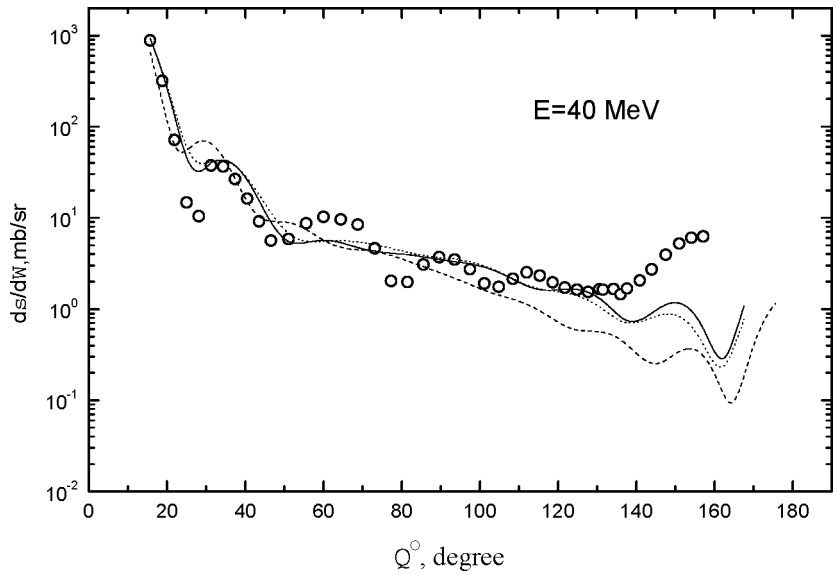
Fig.1. Radial dependence of α-particles potentials of interaction with nucleus ^{7}Li, calculated in the different models. Solid curve - optical model potential; dashed curve - double folding potential; dotted curve - cluster folding potential.

Analyze of experimental data.

For an analyze of experimental angular distributions of elastic scattering it was applied the optical model with the complex potential of interaction, real part of which is based on the scheme, described above, and imaginary one is taken in the Saxon-Woods form only with volume absorption. Thus, an imaginary part of optical potential contains three parameters. An analyze of experimental data is carried out by several stages. On the first stage it is used phenomenological optical model with real and imaginary parts in the Saxon-Woods form and determined an optimal set of optical parameters. At that, the adjustment procedure used the experimental data for forward angles only. As starting parameters of OP it were taken their values from work [13]. In order to find an optimal values of potential depth, the theoretical calculations were carried out at the fixed values of radii r_v = 1.245 fm and r_w = 1.57 fm (set of OP "A").

On the second stage an optimal agreement of theory with the experiment is achieved by varying of parameters of imaginary part of OP and normalization factor N of microscopic real part (set DF). Its difference from unit can indicate about contribution of second order terms on the effective forces to real part of optical potential. At that the folding potential gives a description of experiment comparable with phenomenological OP (see inFig.2-3).

On the third stage were carried out calculations of scattering differential sections on ^{7}Li in the framework of cluster folding model with the same OP set (imaginary part). The results of these calculations are represented in Fig.2-3 (set CF). As seen, that the obtained potential is well reproduced the angular distributions of α -particles in the forward hemisphere (till angles ~70^{0}).



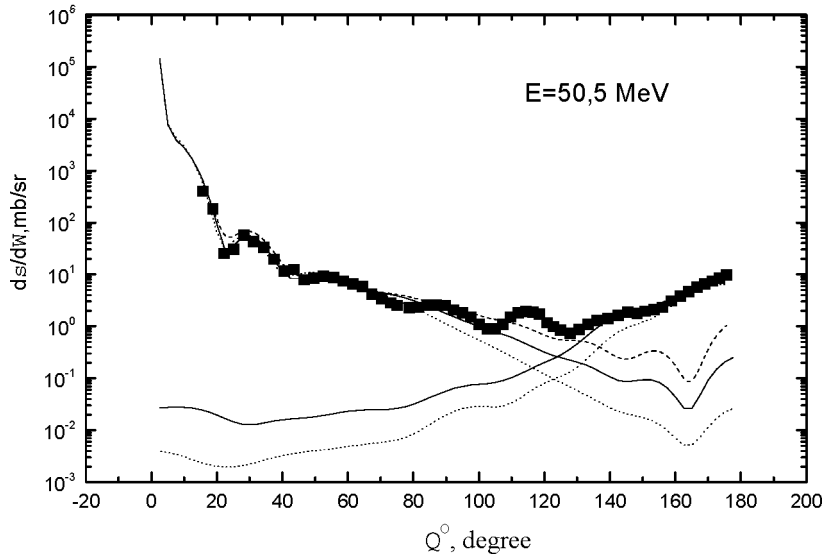


Fig. 2-3 Differential cross sections of α -particles elastic scattering on the ^{7}Li nucleus. Solid curve -calculation under optical model; dashed curve- calculation with the potential of double folding; dotted curve - calculation with the cluster folding potential.

An optimal values of optical potentials and "N" normalization coefficient parameters are represented in Table 1.

Table1. Parameters of optical potentials of α -particle elastic scattering on the nuclei

E, MeV	Type	N	V, MeV	r_v, fm	a_v , fm	W, MeV	a_v, fm	a_w , fm	χ^2	J_v, MeV×fm^3
50,5	A		97.33	1.245	0.776					403
	DF	0.97	102.44	2.469	0.801	21.76	1.570	0.692	6.7	408
	CF	1.04	119.20	1.983	0.878					376
40	A		94.43	1.245	0.779	19.58	1.570	0.747	23.3	392
	DF	0.95	104.47	2.471	0.799					401
	CF	1.04	119.20	1.983	0.878					376

As we can see from the table, an agreement of all 3 calculations - phenomenological and microscopic - is based on the values of volume integrals J_v, belong to the same set in all cases. The values of normalization coefficients are differed from unit for ~3-5%, corresponding for CF and DF potentials.

For removal of theory disagreement with the experiment observed at the backward angles it is required to account the contributions of mechanisms like heavy stripping, exchange process etc.

In particular, the contribution of heavy stripping can be accounted by following scheme: ^{7}Li rest nucleus is decayed on α-particle and triton, and triton is captured by α-projectile. In this case, the stripping mechanism and potential scattering are interfered with each other, but in turn give main contributions on the large and small angles. For calculation of heavy stripping mechanism it was used the famous program(DW) with non zero range of interactions DWUCK5. Spectroscopic factor was chosen as equal to one. On the whole, the mechanism of heavy stripping explains a section raise to backward angles at the energy of 50,5 MeV. At the same time, an account of only heavy stripping contribution can't describe a raise of sections on the backward angles at energies of 40 MeV. For removal of observed disagreement between experiment and calculations in filed of average angle for both energies and disagreement on backward angles at low energy it is necessary to account contributions of other mechanisms as well, like coupled channels, exchange process etc.

CONCLUSION

Let's resume the work main results.

1. In the framework of double folding model based on the full M3Y - effective interaction it was constructed potentials for α-particles, interactive at the energies of 40-50,5MeV with ^{7}Li nucleus -target.
2. There was performed the analyze of α-particles elastic scattering angular distributions on the investigated nucleus using potentials, constructed in the framework of double-folding model and cluster folding. It was received satisfactory description of experimental data with the normalization coefficients for real microscopic optical potentials, which are differed from unit on 3-5%.
3. As regards the calculations of interaction microscopic potentials in the framework of cluster folding model for scattering of α-particles on ^{7}Li nucleus, the following advantages can be pointed:

Firstly, it is significantly simplified the mathematical aspect of problem due to numbers reduction of freedom degree(numbers of coordinate);

Secondly, it is obviously accounted in calculation a pronounced cluster structure of nucleus-target.

4. There was applied an account of contribution of heavy stripping mechanism for explanation of experimental section raise at the backward angles. Due to this mechanism it was possibly to explain the section raise to the backward angles at the energy of 50.5MeV.

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