ENERGY AND MASS DEPENDENCE OF DEUTERONS BY MACROSCOPICALLY OPTICAL MODEL IN RANGE OF COULOMB BARRIER TILL 200 MEV*

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The joint analyze of experimental data of interactions deuterons on nuclei ^{6}Li, ^{16}O, ^{32}S, ^{50}V, ^{51}V, ^{70}Ge, ^{72}Ge, ^{90}Zr, ^{116}Sn in range of Coulomb barrier till 200 MeV is presented. The global parameters as mass and energy dependence of deuterons with energies till 200 MeV by macroscopically optical model of deuterons were analyzed.

Introduction

The reactions of loosely coupled nucleus with many specifications are actively discussed [1 – 3]. The last years there is actual systematical joint study of experimental data by modern phenomenological, semi-microscopic and microscopic approaches for the learning of new information on the structural characteristics of the nuclear matter.

Deuterons have some unique specifications which are influenced on distribution of their interaction with nucleus in frame work of optical model (OM). At the first, there are have loosely coupled structure and the deuteron matter is decayed in special energy. There is the great potential in condition of OM. Secondly, deuterons have sharply asymmetric charge distribution, and this affects their electrical interaction at energies above the Coulomb barrier.

In the framework of OM further there was data of experimental cross section using not only the value absorbing potential and the potential of the surface absorption, as well as their combination. Analyzed data showed that the founded parameters are consistent with each other, and OM gives an acceptable description of the angular distributions of deuterons elastic scattering (ES).

However, there are many cases of parameters of optical potential (OP) which give equally good description of the experimental ES at multiple parameter sets of OP.

The joint analyze of ES deuterons on nucleus ^{6}Li, ^{16}O, ^{32}S, ^{50}V, ^{51}V, ^{70}Ge, ^{72}Ge, ^{90}Zr, ^{116}Sn at different energies and data of total cross sections (TCS), mass and energy dependences of OP parameters are presented in this article.

The Experimental Data and Optical Model

We analyzed experimental data [1, 4] of deuterons ES and their TCS within the deformed potential OM using settlement program SPI-GENOA [5].

There is easy to get a good description of the experimental data as a complete set of components of the nuclear interaction, including the spin-orbit about several parameters. However, not all the parameters found in this way have a physical meaning. Assuming that the potential scattering dominates in the forward hemisphere, there is no view of the spin-orbit interaction; consider

nuclear capacity in its simple form, which includes both bulk and surface absorption:

$$U(r) = -Vf(r) - i\left[W_s f_{W_s} - 4a_D W_D \frac{d}{dr} f_{W_D}(r) \right] + V_C , \qquad (1)$$

the radial dependence is described by Woods-Saxon form factor:

$$f_i(r) = \left(1 + \exp\left(\frac{r - r_i A_t^{\frac{1}{3}}}{a_i} \right) \right)^{-1} . \qquad (2)$$

V, *WS*, *WD* – the depth of real and imaginary parts of the OP with surround (*S*) and surface (*D*) absorption; r_i, a_i – corresponding reduced radius and diffuseness. The last term in equation (1) is the Coulomb potential of a uniformly charged sphere of radius [*fm*], A_t – the mass of the target nucleus.

OP parameters corresponding to optimal matching of the experimental and theoretical values of the cross sections are found by minimizing the value:

$$\chi^2 = \frac{1}{N_э} \sum_{i=1}^{N_э} \left[\frac{\sigma^T(\theta_i) - \sigma^э(\theta_i)}{\Delta\sigma^э(\theta_i)} \right]^2 ,$$

where $N_э$ – number of data points in the angular distribution, σ^T and $\sigma^э$ – calculated and measured value of the differential scattering cross section at an angle θ_i and $\Delta\sigma^э$ – uncertainty $\sigma^э(\theta_i)$.

By the parameters of the geometry of the real part of the OP (radius and diffusivity), the parameters of volume absorption (W_S, r_S, a_S) and the radius of the potential surface absorption (r_D) were fixed, and varied only three remaining parameters: *V*, W_D and a_D. OP radial parameters were fixed values: r_V =1,186 *fm* and r_s = 1,54 *fm*, r_D =1,083 *fm*. The number of partial waves reached counted (35 – 75) depending on the mass of the target nucleus and the deuteron energy. Optimal parameters and their corresponding χ^2 are given in Table 1. Fig. 1 shows a quite satisfactory description of the experimental deuterons ES with energy 171 *MeV* on nuclei with mass numbers A = (6 – 116). Fig. 2 shows a satisfactory agreement between the experimental [6 – 10] and theoretical TCS at different deuteron energies.

The Mass and Energy Dependence

The mass and energy dependence of the parameters of the OP for deuterons on nuclei at the range A = (6 – 116) were studied.

The linear dependence on the mass number of target nuclei was obtained by

Table 1. The Optimal parameters of deuterons at energy 171 MeV

Nucleus	V, *MeV*	a_V, *fm*	W_S, *MeV*	a_S, *fm*	W_D, *MeV*	a_D, *fm*	χ^2
^{6}Li	47.514	0.720	6.312	0.972	4.575	0.587	2.126
^{16}O	60.481	0.733	3.436	0.736	6.790	0.676	2.337
^{32}S	54.722	0.800	4.638	1.013	10.85	0.897	2.822
^{50}V	60.159	0.793	8.019	0.880	11.28	0.542	3.448
^{51}V	61.645	0.811	8.944	0.764	12.31	0.501	1.533
^{70}Ge	60.201	0.845	4.531	0.681	13.32	0.664	5.53
^{72}Ge	57.671	0.873	4.605	0.745	15.65	0.687	4.211
^{90}Zr	61.332	0.896	7.555	0.600	16.88	0.496	3.367
^{116}Sn	67.183	0.884	6.878	0.771	17.95	0.642	1.778

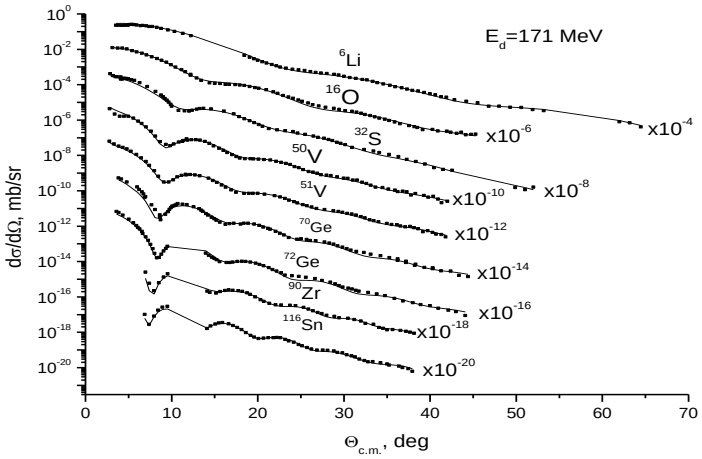

Figure 1. Differential cross sections for elastic scattering of deuterons at energy 171 *MeV*

OP method after the selection of optimal parameters of least squares (Fig. 3) and analytically data is presented in:

$$V=1.625(ZA^{-1/3})+49.52;\ W_S=0.966\ A^{1/3}+2.604;$$

$$W_D=4.519\ A^{1/3}-3.971;\ a_V=0.0623\ A^{1/3}+0.589.$$

The symbols as experimental data, solid lines – theoretically calculated data (within OM) with potentials are presented in Table 1.

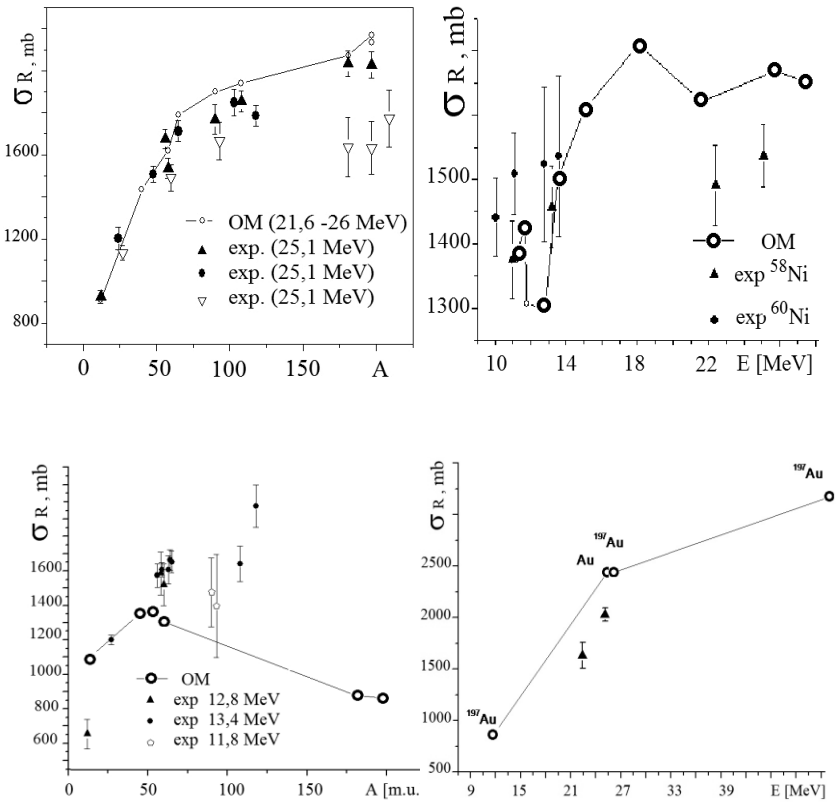

Figure 2. **Left:** *Mass dependence* : *a* (top) – total reaction cross sections for deuterons at E_d = (21 – 26) *MeV*, the experimental data: ▲ – 25.1 *MeV* [1], ● – 25.3 *MeV* [1], ∇ – 22.4 MeV [2], the theoretical value of the SEP calculated by OM are shown by the solid line; *a* (lower) – total reaction cross sections for deuterons at E_d = (11.8 – 13.6) *MeV*.

Right: *Energy dependence*: *b* (top) – the energy dependence of the TCS for gold: experimental data – triangles [1, 2], the theoretical value of the TCS calculated by OM are shown by the solid line; *b* (bottom) – the energy dependence of the TCS for ^{58}Ni, ^{60}Ni: experimental data – triangles [3, 4, 5], the theoretical value of the TCS calculated by OM are shown by the solid line.

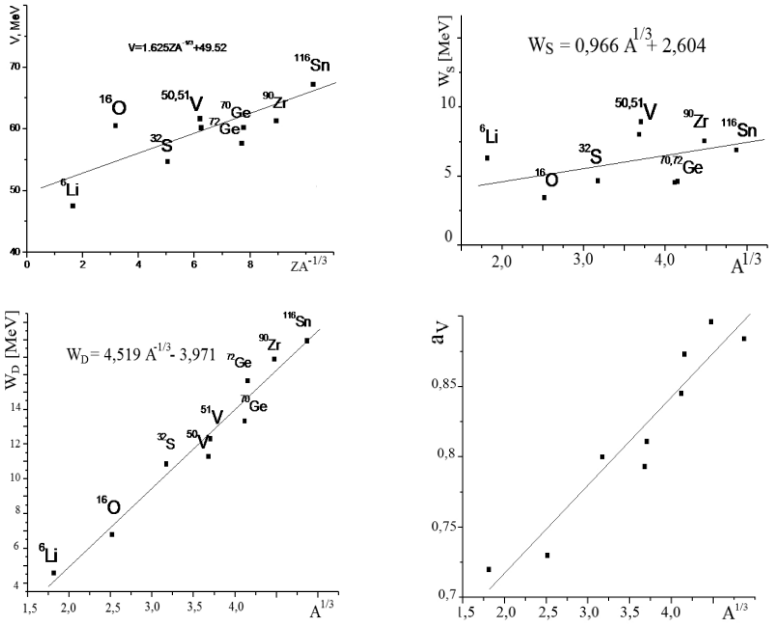

Figure 3. Mass dependence of OP parameters at energy E_d=171 *MeV*

Conclusions

The joint analysis of the ECS and TCS deuterons in the standard OM at different energies were done. The global mass and energy dependence in the energy range up to 200 *MeV* have received on the basis of the found optimal and physically accurate parameters of the OP.

References

1. L.F. Canto et. al., *Phys. Rep*. **424**, 1 (2006).
2. N. Keely et. al., *Progress in Part and Nucl. Phys.* **59**, 579 (2007).
3. Yu.E. Penionzhkevich. *Phys. Atomic Nuclei (Yadernaja Fizika).* 1 (2009).
4. A. Korff, P. Haefner, A.M. van den Berg, et. al., *Phys. Rev.* **C70**, 067601 (2004).
5. F.G. Perey, SPI-GENOA an optical model search code. NBI version (1976).
6. S. Mayo, W.Schimmerling, M.J. Sametband, R.M. Eisberg, *Nucl.Phys.* **62**, 393 (1965)
7. G. Igo, B. Wilkins, *Phys.lett.* **3**, 48 (1962).
8. K. Beapark, W.R. Graham, G.Jones, *Nucl.Phys.* **73**, 206 (1965).
9. A. Budzanowski, L. Freind, K. Grotowski et. al., *Nucl.Phys*. **49**, 144 (1963).
   L.V.Dubar, O.F.Nemez, L.I.Slusarenko, V.V. Tokarevsky, *Conf. XXII Nuclear spectroscopy and structure of nuclear*, 68 (1972).