TOTAL REACTION CROSS SECTIONS OF ^{4}He+^{28}Si INTERACTION AT 2-50 AMeV

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Analysis of energy dependencies for experimental total ^{4}He+^{28}Si reaction cross section employed various parameterizations. In order to describe them in the energy range of 70-200 MeV one should introduce a parameter that considers transparency of a nucleus. At energies E_{α} < 50 MeV there is a discrepancy in total reaction cross section for theoretical and experimental data. The value σ_R decreases from 400 mb down to 60 mb when α-particle’s energy increases from 10 to 40 MeV.

Experimental data on reaction cross sections for nuclear-nuclear interactions provide important information on parameters of the potentials and structure characteristics of the nuclei contributing considerably to data on elastic and inelastic scattering. Since α-particle is a core for light exotic nuclei (^{6,8}He), it is of interest to analyze systematically the empirical energy dependence for total ^{4}He+^{28}Si reaction cross sections (TRCS) in the energy range from the Coulomb barrier (B_c ~ 6 MeV) to medium energies of about 200 MeV. Looking up into published experimental data one can reveal that the reaction ^{4}He+^{28}Si is the only with thoroughly measured TRCS excitation function (σ_R) in this wide energy diapason. Experimental data on TRCS from B_c up to 101.2 MeV were obtained by us at the isochronous cyclotron of the Institute of Nuclear Physics (Almaty, Kazakhstan) [1,2] and at the cyclotron K-130 of the University of

Juvaskyla, Finland [3]. The energy dependencies of σ_R on the nuclei ^{28}Si at average energies of 69.6 – 192.4 MeV were studied in the works [4,5]. The work [6] presents data on σ_R for the nucleus ^{28}Si obtained at the accelerator U-240 of the Institute of Nuclear Research in Kiev, Ukraine at energy E_α = 96 MeV and studies thoroughly the mass-dependence of α-particle TRCS at the energy E_α = 96 MeV.

At low energies TRCS are proportional to nuclear sizes only within a limited diapason of mass numbers making this band wider at higher energies of accidental particles. TRCS behaviour at low energies is determined by the ratio of the Coulomb barrier and energy of ^{4}He-particle. Further increase of E_α results in decreased wavelength of an α-particle with increased role of nucleon-nucleon interactions (their interaction sections decrease at higher energies) making TRCS lower at higher energies of ^{4}He-particles.

The following parameterization of TRCS has been accepted at low energies:

$$\sigma_R = \pi R_{in}^2 \cdot (1 - B_c / E_\alpha), \quad (1)$$

where R_{in} – interaction radius. In case of ^{4}He-particle $R_{in} = r_o (A_t^{1/3} + A_\alpha^{1/3})$, A_t – mass of the target nucleus, A_α – mass of α-particle, r_o – parameter of radius.

At higher energies with $E_\alpha >> B_c$ TRCS achieve the geometrical limit of the effective cross-section at the energy E_α ~ 60–70 MeV. Upon achieving this geometrical limit and at further energy increase there is decrease in TCS [7, 8]. Section σ_R minimum is localized at energy ~ (250–300) MeV/nucleon [7, 8] for nuclei ^{12}C, ^{60}Ca, ^{64}Cu; probably, the same values should be observed for ^{28}Si. De Broglie wave length of a medium-energy ^{4}He-particle is several times less than size of a target nucleus and is compared or smaller than average distance between nucleons of a nucleus. Therefore a particle "feels" the nucleons in a nucleus and interacts with them. So, interaction character is now different, and a particle does not interaction of with a nucleus as a whole, but it interacts with separate nucleons. A nucleus becomes partially transparent for incident particle accompanied with nucleus "blooming" that starts, probably, far before achieving the geometrical limit. Introducing into the Eq. (1) a factor (1-T) where T denotes transparency of a nucleus one can take into account the "blooming":

$$\sigma_R = \pi R_{in}^2 \cdot (1 - B_c / E_\alpha) \cdot (1 - T). \quad (2)$$

In (2) the interaction radius R_{in} depends not only on the mass numbers A_t and A_α, but on energy asymmetry as well.

Discrepancy in calculated and experimental parameterizations can be explained as follows. First, parameter of the radius r_o for ^{4}He-particle differes from its value for the nucleus ^{28}Si. Second, in the energy range beyond the geometrical limit σ_R (>70 MeV) influence on TRCS of Coulomb field of the nucleus is poorly described by the factor $(1–B_c/E_\alpha)$. Above the ^{4}He-particle energy of about 20 MeV/nucleon one could probably neglect the Coulomb factor $(1–B_c/E_\alpha)$ in Eq. (2) and use the following:

$$\sigma_R = \pi R_{in}^2 \cdot (1 - T). \quad (3)$$

There are other ways to take into account transparency of nuclei, for instance:

$$R_{in} = R_t + R_\alpha - \Delta R_{t\alpha}, \quad (4)$$

where the term $\Delta R_{t\alpha}$ considers overlapping of densities for colliding nuclei and may be assigned to radius of any of the nuclei in the Eq. (4). If $\Delta R_{t\alpha}$ is referred to radius of an incident ^{4}He-particle, then decrease of its radius R_α at increasing energy E_α may be considered as "blooming" of target nuclei. Introducing $R_\alpha - \Delta R_{t\alpha} = R_{ef}$ one can obtain another expression for TRCS:

$$\sigma_R = \pi\left(r_0 \cdot A_t^{1/3} + R_{ef}\right)^2. \tag{5}$$

Fig. 1 presents energy dependence of TRCS for ^4He+^{28}Si. Symbols denote experimental data [1-6] and solid curves – parameterizations [8-12].

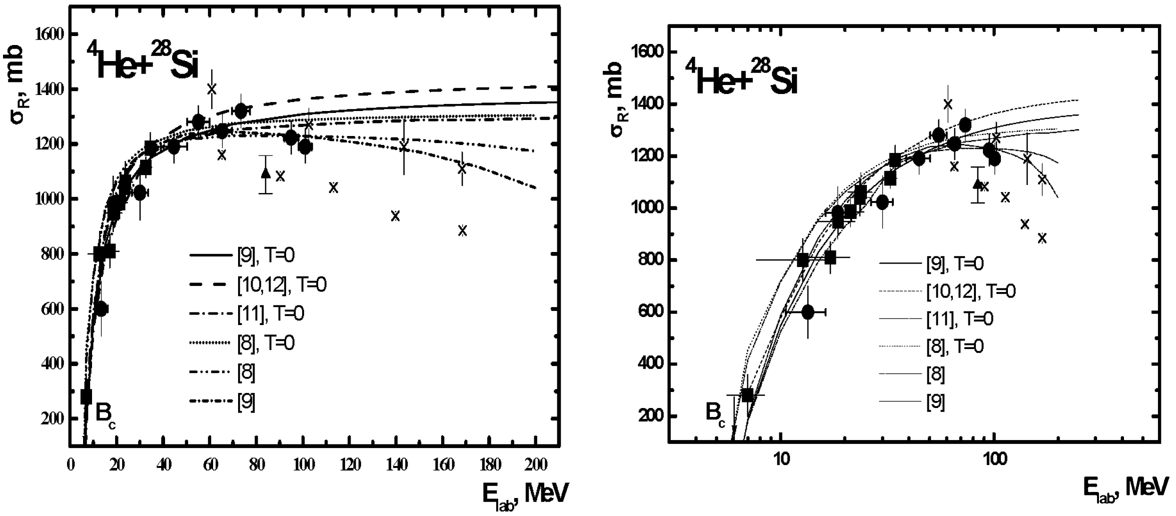

Fig. 1. Energy dependence of TRCS for ^4He-particles at their interaction with the nucleus ^{28}Si. Black squares denote experimental TRCS from works [1,2]; black dots – from [3]; daggers – from [4,5]; triangles – from [6]. Curve represents parameterization of energy dependence with expressions from the works [8–12].

Analysis of energy dependencies for obtained experimental TRCS employed their various parameterizations. Parameterizations from the works [8-12] satisfactorily describe TRCS energy dependence; at that the parameter r_o should be within the limits (1.38–1.44) fermi. In order to describe TRCS in the energy range of 70-200 MeV one should introduce a parameter (1-T) that considers transparency of a nucleus. It should be noted that at higher energies when $E_\alpha >> B_c$ experimental TRCS achieve their maxima at energy E_α ~ 60–70 MeV and maxima in the parameterizations [8-12] are achieved at energies E_α = 40–50 MeV.

We have performed analysis of experimental angular distributions of elastic scattering for α-particles and of tendencies for TRCS changes for the nucleus ^{28}Si for the energy range E_α = 14.47–240 MeV within the macroscopic optical model (MOM) [13] and semi-microscopic folding model (SFM) [14]. As initial values for the parameters there were taken ones recommended in [15] for α-particle scattering. On Fig.2 one can see quite good description of experimental angular distributions for elastic scattering within the MOM and SFM models.

Obtained within these models potentials were used for calculations of total reaction cross sections. As one can see from fig.3, in the energy range of 50 – 240 MeV MOM and SFM describe well the energy dependence of TRCS. At energies E_α < 50 MeV there is discrepancy in TRCS for theoretical (MOM) and experimental data, which decreases from 400 mb down to 60 mb when α-particle energy increases from 10 to 40 MeV.

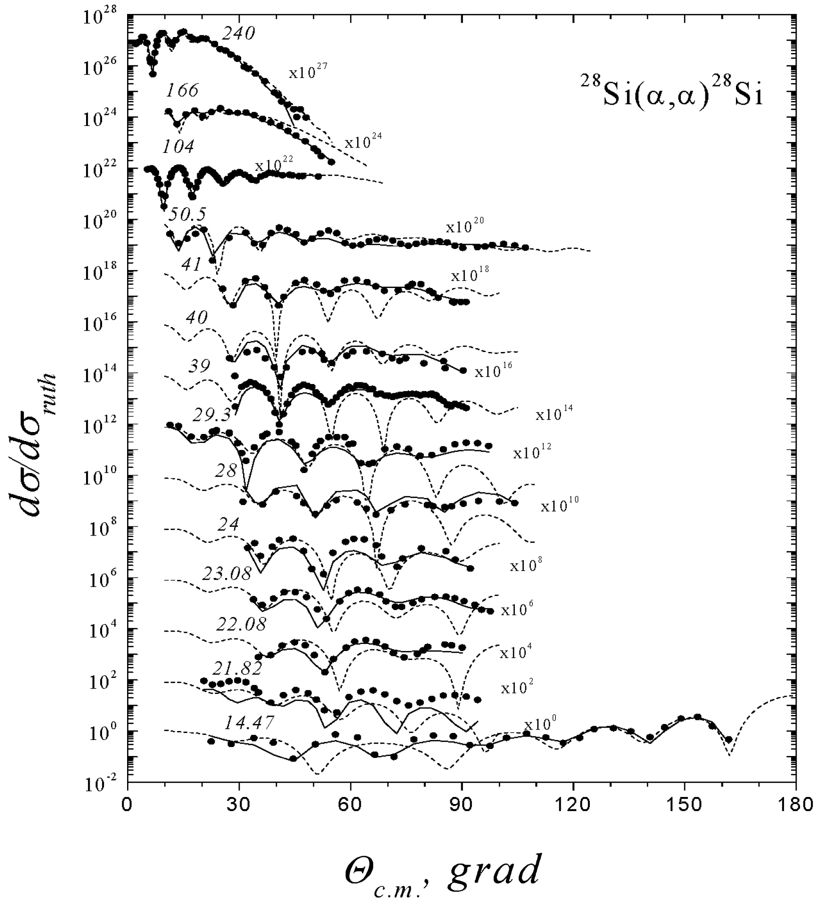

Fig. 2. Angular distributions of differential cross sections of elastic scattering for α-particles with energies of 14.47–240 MeV on nucleus ^{28}Si. Dots denote experimental data; solid curves – MOM, dash curves – SFM.

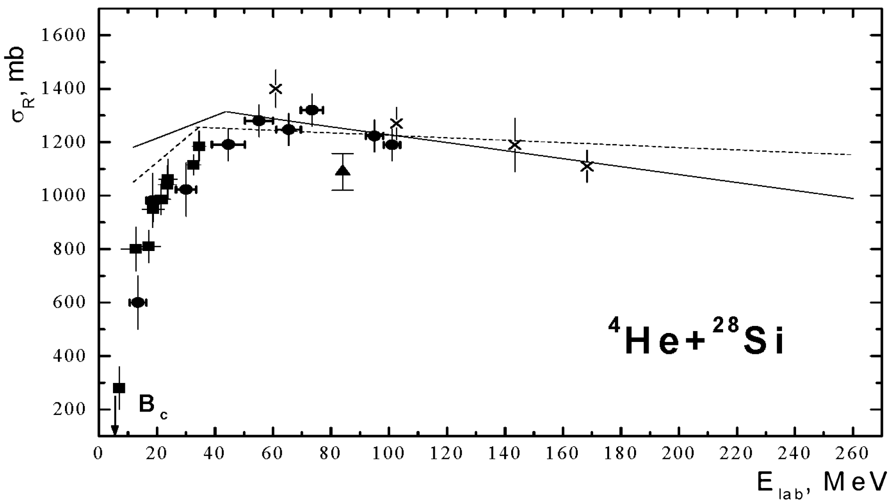

Fig. 3. Energy dependence of TRCS for ^{4}He-particles at their interaction with the nucleus ^{28}Si. Black squares denote experimental TRCS from works [1,2]; black dots – from [3]; daggers – from [4,5]; triangles – from [6]. Solid curves represent MOM, dash curves – SFM.

At analysis of discrepancies between experimental and theoretical TRCS on should take into account the following. Within MOM two main values are calculated: differential section of elastic potential scattering $\frac{d\sigma_{el}^{T}(\theta)}{d\Omega}$ and absorption section σ_a, while in experiments one measures differential sections of elastic scattering $\frac{d\sigma_{el}^{Э}(\theta)}{d\Omega}$ and reaction section σ_R. At that one should take into account the following:

a. for differential sections: $\frac{d\sigma_{el}^{Э}(\theta)}{d\Omega} = \frac{d\sigma_{el}^{T}(\theta)}{d\Omega} + \frac{d\sigma_{el}^{ce}(\theta)}{d\Omega}$, where $\frac{d\sigma_{el}^{ce}(\theta)}{d\Omega}$ - differential cross section for elastic scattering with formation of a compound nucleus;

b. for absorption sections and reactions: $\sigma_R = \sigma_a - \sigma_{ce}$, where σ_{ce} – integral section of elastic scattering with formation of a compound nucleus.

Contribution from the compound nucleus mechanism at energies $E_\alpha > 20$ MeV is negligible in comparison with error in determination of σ_R and does not influence the agreement between the theory and experiment.

What other mechanisms can explain such difference in TRCS? Possibly, one would introduce additional terms into optical potential, in particular, L-splitting potential, etc.

REFERENCES

1. M. K. Baktybaev, K.A. Kuterbekov, Yu.E. Penionzhkevich, Yu.G. Sobolev, et al., *Yad. Fiz.* **66**, 1 (2003) (in Russian).
2. V.Yu. Ugryumov et al., Book of Abstracts of 8-th International Conference NN-2003, June 17-21, Moscow, Russia. V.Yu. Ugryumov et al., Preprint JINR E7-2003-193, Dubna, 2003, Submitted to "Nucl. Phys. A".
3. V.Yu. Ugryumov et al., Preprint JINR P15-2003-175, Dubna, 2003, Submitted to "Nucl. Phys. A". (in Russian).
4. A. Ingemarsson, J. Nyberg, P.U. Renberg et al., *Nucl. Phys.* A **676**, 3 (2000).
5. A. Auce, R.F. Carlson, A.J. Kox et al., *Phys. Rev.* C **50**, 871 (1994).
6. O.F. Nemets, L.I. Slusarenko. *Izv. Rus. Akad. Nauk, Ser. Fiz.*, **54**, 2105 (1990) (in Russian).
7. P.J. Karol, *Phys. Rev.* C **11**, 1203 (1975).
8. R.M. DeVries, J.C. Peng, *Phys. Rev.* C **22**, 1055 (1980).
9. P.E. Hodgson. Nuclear heavy ion reactions. Oxford: Clarendon Press, 1978.
10. C.Y. Wong, *Phys. Rev. Lett.* **31**, 766 (1973).
11. S. Kox, A. Gamp, R.Cherkaoui et.al., *Nucl. Phys.* A **420**, 162 (1984).
12. Yu.V. Kibkalo, Ukr. J. Phys. **25**, 1565 (1980).
13. F. Perey, SPI-GENOA an optical model search code (unpublished).
14. O.M. Knyazkov, I.N. Kukhtina, S.A. Fayans, *Nucl. Phys.* A **61**, 287 (1998).
15. K.A. Kuterbekov, I.N. Kukhtina, T.K. Zholdybayev, Yu. E. Penionzhkevich et al, Preprint JINR E7-2002-220, Dubna, Russia, 2002.