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TOTAL REACTION CROSS SECTION OF SILICON INDUCED BY ^{4}He IN THE ENERGY RANGE 3–10 MeV/u

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The value of the total reaction cross section (σ_R) is essentially interconnected with differential cross section of elastic scattering. While the σ_R could be determined by transmission method, different optical model are commonly used to describe azimuthal distributions of elastic scattering. Therefore we experimentally determined total cross section as a function of particle energy and used obtained data as independent test of optical models fitted to experimentally obtained azimuthal distributions of elastic scattering deduced from published papers [1,2].

The experiment was carried out using ^4He ion beam at 40 and 50 MeV bombarding energies delivered by the U150M accelerator of the Institute of Nuclear Physics of Kazakhstan Republic. The 10 pnA ^4He beam impinged on a self supported ^{12}C scattering target 0.45 mg/cm^2 thick. The scattered α-

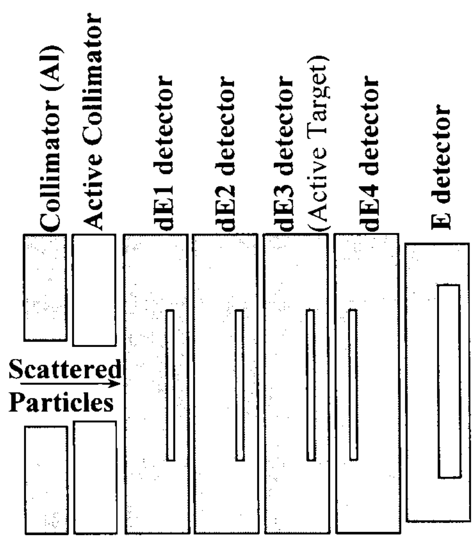

Fig.1. Detector geometry

particles were detected by a telescope consisting of two collimators and five silicon detectors of different thicknesses closely adjacent one to another, see Fig.1. The telescope was moved in the horizontal plane relative to the beam direction in the angular range from 20° to 64° to change incident energy of α-particles. This range was chosen to maximize the ratio of the elastic to the inelastic channel yields in (^{4}He,^{12}C) reaction.

The employment of passive and active collimators allows focusing elastically scattered α-particles to the central part of detectors with lowest distortion due to rescattering. The diameter of passive collimator was 10 mm. Si(Li) ring detector with 8 mm inside diameter and 3 mm thick was used as active collimator. The 5 μm dead layer of inside ring of the active collimator was obtained by shifting spectra from ^{226}Ra α-radioactive source. The first two dE1 and dE2 detectors were used to separate elastically-scattered α-particles with an energy $E\alpha$, which consequently could induce various nuclear reactions in the dE3 detector and hence change their energy. The reaction products were selected using a dE3 vs dE4 two-dimensional plot. This is demonstrated in Fig.2 and Fig.3a,b. While in Fig.3a whole spectrum of α-particles scattered from primary carbon target is shown, selection of elastically scattered α-particles, see vertical and horizontal lines in Fig.2, results in spectrum shown at Fig.3b. Here events corresponding to the α-particles undergoing nuclear reaction in dE3 detector are located around the peak of corresponding α-particles not undergoing nuclear reaction. If we denote number of particles detected in the peak as I and number of particles with $E\alpha$ hitting dE3 detector as I_0, when it holds

$$I = I_0 e^{-\sigma R(E\alpha)\, N}.$$

Here N is number of Silicon nuclei in detector dE3 per cm^2 and $\sigma_R(E\alpha)$ is total reaction cross section of α-particles with an energy $E\alpha$ in Silicon. I_0

was determined as number of events in rectangle corresponding to the used selection in Fig.2.

Thickness of detectors dE1 and dE2 were 100 μm, dE3 and dE4 – 160 μm. Detectors dE1 and dE2 were thinly to reduce the number of nuclear reactions in dE1 and dE2. The energy resolution of dE3 detector determined by α-radioactive source was 80 keV. The width at half-height of the energy

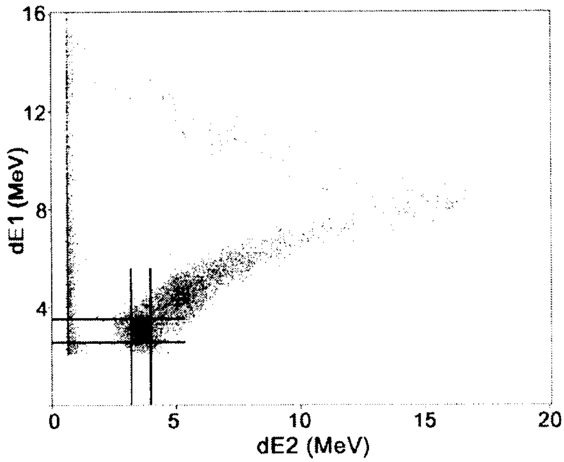

Fig.2. Scatter plot of dE1-dE2 detectors.

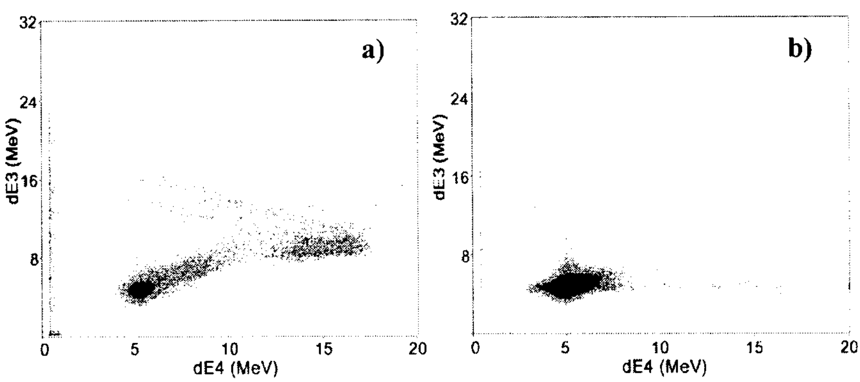

Fig.3a,b. Scatter plot of dE3-dE4 detectors: (a) without any conditions, (b) with condition shown in Fig.2.

distribution at dE3 comprised from 350 to 440 keV depending on $E\alpha$. Experimental energy spread did not allow separating the inelastic channels with excited states of ^{28}Si from the peak of elastic scattered α-particles. According to our estimations the contribution to the total cross section due to excitation of 2+ level of ^{28}Si comprises up to 30 mb at 104 MeV α-particles [3]. Reaction products scattered at backward angles were not taken into account. Their production cross section was less then 3% of σ_R, which is comparable to the statistical errors.

Values of the measured σ_R are shown as black filled squires in Fig.4. The spline of calculated σ_R values were obtained on the base of macroscopic optical model (OM) and semi-microscopic folding-model (SFM) [4] analysis of elastic scattering data $^{28}Si(\alpha,\alpha)^{28}Si$ also shown in fig.4 as solid and dotted lines respectively. It should be noted that our efforts to describe simultaneously with the same set of parameters of OM and SFM both the experimental differential section of elastic scattering and the values of measured σ_R were not successful. Values of optimal OM and SFM parameters obtained from the best fits of angular distributions of elastic scattering reproduce unsatisfactorily of the σ_R experimental values.

Analysis of experimental differential cross sections for the elastic scattering of α-particles and trends of energy dependence σ_R on Silicon was carried out for the energy range E_α = 14.5-50.5 MeV within the framework of optical model using the code SPI-GENOA [5]. Recommendations for α-particles scattering in the energy range up to 80 MeV proposed in the work [6] were adopted as initial values for optical potential (OP) parameters with Woods-Saxon form-factors. The OP parameters were selected in such way, in order to get the best correspondence between theoretical and experimental values of differential and total reaction cross-sections. The

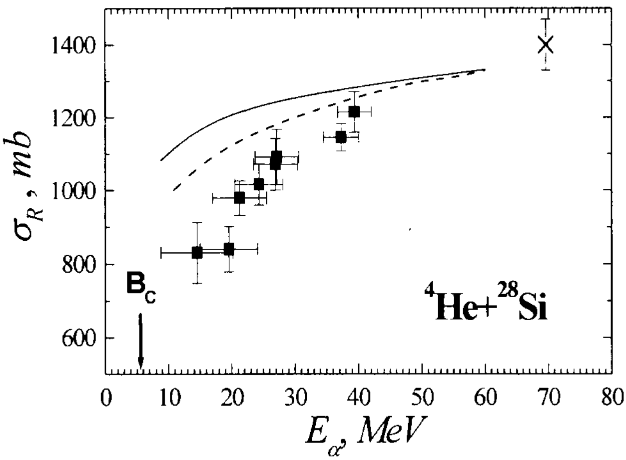

Fig.4. Energy dependence of σ_R for α-particles on ^{28}Si. Experimental data: black squares – present work, cross – from [7]. Calculated values: solid line – macroscopic optical model, dotted line – semi-microscopic folding-model. Arrow B_C shows a height of the Coulomb barrier.

Table 1. Optical potential parameters for the elastic scattering of α-particles at ^{28}Si at different energies (r_v = 1.243 fm, r_w = 1.567 fm).

E_α, MeV	V, MeV	a_v, fm	W, MeV	a_w, fm	$J_R/4A$, MeV·fm^3	χ^2/N	σ_R, mb
14.5	131.36	0.84	3.73	1.08	393	10.0	1163
23.1	122.53	0.76	8.89	0.79	349	12.7	1254
28.0	111.70	0.77	16.01	0.52	317	24.1	1146
41.0	116.94	0.77	15.97	0.60	331	7.8	1208
50.5	108.15	0.85	20.74	0.71	325	11.4	1355

Table 2. Values of SFM parameters for folding-potentials.

E_α, MeV	φ_v	N_w	φ_w	σ_R, mb
14.5	-0.05	0.05	0	979
23.1	-0.01	0.11	0	1203
28.0	0.03	0.14	0.02	1176
41.0	0.02	0.17	0	1263
50.5	0	0.26	0.01	1251

search for optimal OP parameters was carried out using minimization of the value χ^2/N. Coulomb radius was equal to r_c=1.25 fm. Table 1 presents the obtained values of the OP parameters, values χ^2/N, volume integral J_R and calculated values σ_R. Table 2 present semi-microscopic folding-model parameters and calculated values σ_R obtained using the analysis of experimental angular distributions for elastic scattering of α-particles at the same energies.

The energy dependence of total reaction cross section for α-particles on ^{nat}Si has been directly measured by the transmission method. The measured σ_R supplements the available literature data. Optical model predictions are in agreement with total cross section data at higher energies, see experimental point at 69.6 MeV taken from paper [7]. At low energies studied in this work this is not the case, as difference between calculated and measured values gradually increases with the decrease of $E\alpha$, see Fig.4.

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Полное сечение реакции ионов ^{4}He с ядрами кремния в диапазоне энергий 3–10 МэВ/А

Энергетическая зависимость полного сечения реакции α-частиц с ядрами ^{nat}Si была измерена методом прохождения. Из полученных данных видно, что экспериментальная энергетическая зависимость σ_R отличается от теоретических предсказаний при низких энергиях. Поправки к σ_R, связанные с возбуждением первого уровня кремния α-частицами, были вычислены на основании данных по угловым распределениям этой реакции.

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Total Reaction Cross Section of Silicon Induced by ^{4}He in the Energy Range 3–10 MeV/u

The energy dependence of total reaction cross section for α-particles on ^{nat}Si has been directly and accurately measured by the transmission method. These data show that σ_R has different energy dependence from theoretical predictions at low energies. The σ_R corrections due to inelastic scattering to the first excited state were made by integrating corresponding angular distributions.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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