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INVESTIGATION OF LARGE ANGLE ELASTIC AND INELASTIC α PARTICLES SCATTERING ON Si ISOTOPES*

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The distributions of differential cross sections for backward angles in case of three (^{28,29,30}Si) silicon isotopes were measured for five energies around 27 MeV. The comparison between existing data and measured data was done. Quantitative analysis of the data was made.

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1. Introduction

The backward-angle enhancement of elastic and inelastic α-scattering cross section for light- and medium-mass target nuclei has been observed for the first time more than twenty years ago [1–5]. For several nuclei the magnitude of cross sections for large angles was comparable with or often greater than that for the forward direction. These enhancements show an especially strong isotope dependence (as an example can serve the elastic α-particle scattering on calcium isotopes). On the other hand the excitation

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functions for backward angles often showed a strong resonance structure. Since then there has been much effort to explain this phenomenon which used to be called sometimes an anomalous large angle scattering (ALAS). Many models to describe the anomalous α-scattering have been proposed (see for example [6] and [7]). Attempts towards systematics of ALAS has also been published [8].

Elastic and inelastic α-particle scattering on ^{28}Si nucleus is one of the examples of an occurrence of ALAS. This particular case has been studied in several papers [9–13].

Present paper is an extension of our previous work concerning investigation of reaction mechanism observed in elastic and inelastic scattering of alpha particles on ^{28}Si nuclei [14–16]. The aim of this investigation was to search for ALAS in silicon isotopes at energies around 27 MeV.

2. Experimental procedure

The experimental measurements were performed in the Institute of Nuclear Physics in Cracow. The alpha particles beam of energies between 26.3 and 28 MeV with intensity around 10 nA was supplied by the U-120 cyclotron. The beam energy resolution was within the range from 150 to 200 keV. A schematic view of the scattering chamber is shown in Fig. 1. Two collimators (ϕ 3 mm and 2 mm) mounted in ion-guide tube 100 cm apart were used to shape the beam. The spot diameter on the target was about 2 mm. Two versions of electronic set-up which were used in the course of the experiment are presented in Figs 2(a) and 2(b).

A self-supporting ^{nat}Si foil (93% ^{28}Si) of thickness 141 μg/cm^2 was used as ^{28}Si target. Two other silicon targets were manufactured by the evaporation of SiO_2 enriched in ^{29}Si (97%) and ^{30}Si (95%) to the thicknesses of 175 μg/cm^2 and 111 μg/cm^2, respectively. All silicon targets used in the experiment were prepared by the Target Laboratory of the Munich University. Additionally two ^{12}C targets of thicknesses 21 μg/cm^2 and 20 μg/cm^2 were used for beam energy measurements.

Scattered alpha particles were registered by the position sensitive detector (PSD), produced by the ORTEC, which was placed in the region of backward angles as close as possible to the beam. The angular range covered by the sensitive surface of the PSD was between 161° and 173° in the laboratory system. This type of detector allows to determine position as well as energy of registered particle. Parameters of PSD are given in Table I.

TABLE I

Parameters of PSD

sensitive surface	51 × 8 mm
thickness of sensitive layer	0.5 mm
energy resolution	0.1 MeV
position resolution	0.38 mm
working voltage	+170 V
working temperature	$-30° + 25°$
vacuum	$10^{-4} \div 10^{-5}$ T

The angular calibration of PSD has been performed independently by two methods. In the first method a source of light was placed in target position, while the angle was determined by moving a small diaphragm in front of PSD. In the second method a rectangular diaphragm with 1 mm wires was placed in front of PSD, perpendicularly to the reaction plane. The angular positions of wires were precisely measured. In the registered two-dimensional spectrum one sees "shadows" corresponding to the positions of wires.

The energy calibration of PSD has been obtained with a standard α--MIX source.

Another solid state detector of 500 μm thickness was placed at 158° (lab). It served as a monitor detector for beam energy measurements and for cross section normalization as well. The beam energy was measured by applying a kinematic method to alpha particles scattered in this direction from thin carbon target.

Two versions of electronic set-up were used during the experiment. In the first one the ORTEC PSD Analyser (No. 464) has been used (see Fig. 2(a)). The role of this analyser was to handle rough E and $E \times X$ pulses from PSD. Next they were registered as pairs of energy and position pulses in the event-by-event computer acquisition system. The weakness of this set-up was the non-linearity of PSD Analyser which took place in the whole energy range. In the second version of the electronic set-up an event consisted of a pair of pulses E and $E \times X$ from PSD directly (see Fig. 2(b)). They were registered event-by-event on a tape. Later the energy and position of registered particles were reconstructed in the off-line analysis.

The data aquisition system was based on SM-4 minicomputer (compatible with PDP-11). A program specially written for this purpose has been applied. The off-line analysis has been done partly on SM-4 and partly on a PC.

Fig. 3(a) presents a typical two-dimensional spectrum of alpha particles

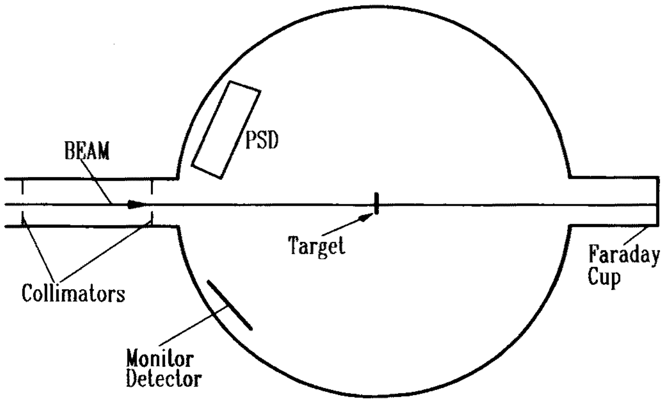

Fig. 1. Schematic view of the scattering chamber.

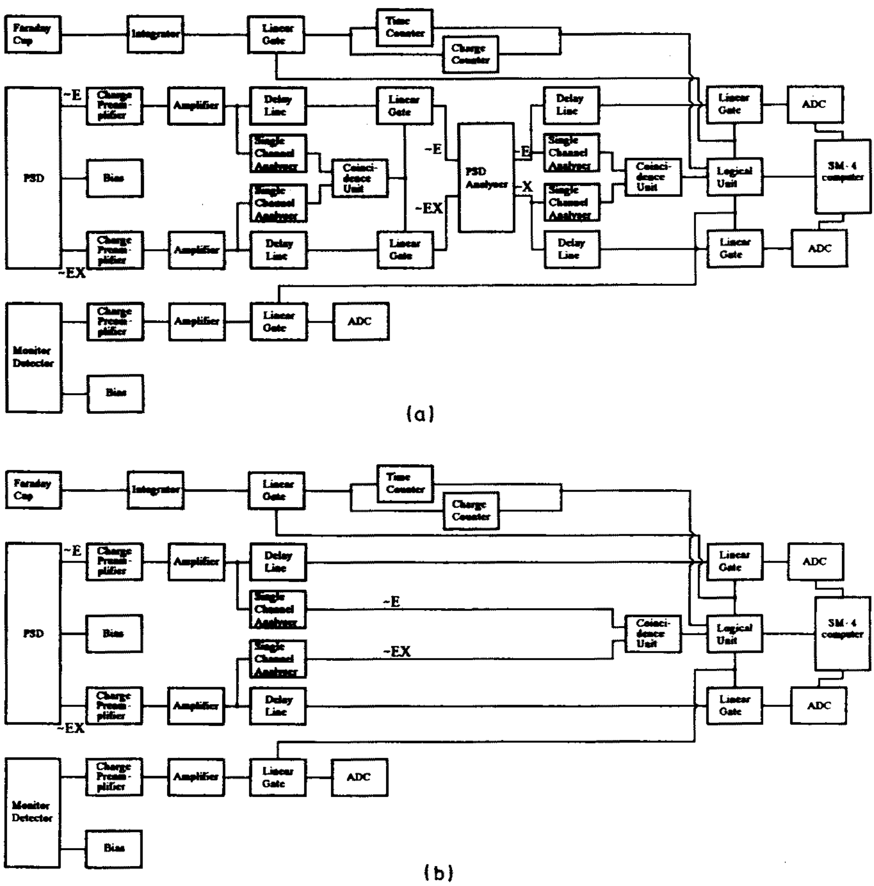

Fig. 2. Block diagram of the electronics. (a) with PSD Analyser, (b) without PSD Analyser.

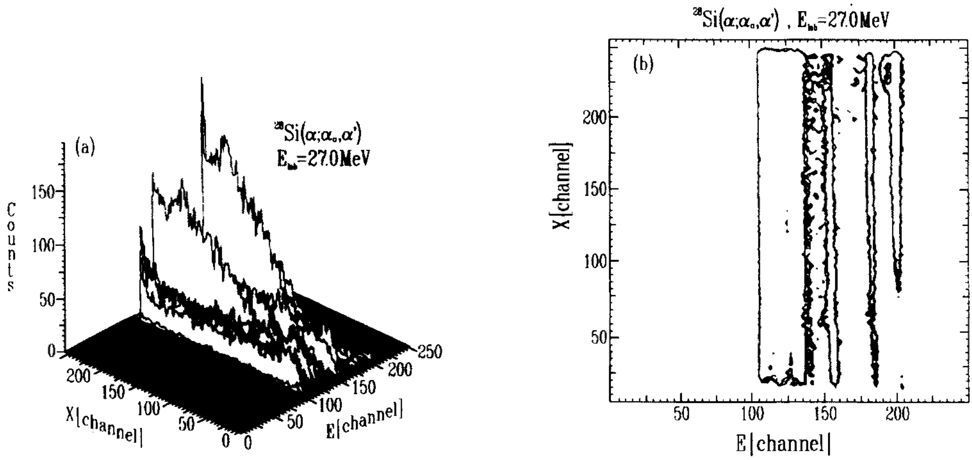

Fig. 3. Scattering of α particles on ^{28}Si at E_{lab}=27.0 MeV. (a) Two-dimensional spectrum of emerging α particles. (b) Contour plot of the same spectrum.

registered in PSD obtained in a standard off-line analysis. It corresponds to α + ^{28}Si scattering. Fig. 3(b) gives a contour plot representing the same spectrum. From these two figures one sees that the spectrum is clean enough, allowing an easy separation of elastic and inelastic transitions leading to the low lying excited states in ^{28}Si. For the other two isotopes the quality of spectra was very similar.

The absolute values of cross sections were determined by normalisation to the previously measured ^{28}Si(α; α_0, α') data at 26.6 MeV [15]. In these calculations the PSD solid angle has been determined and the effect of parallax has been taken into account. When it was necessary, distortions caused by non-linearity of PSD Analyser have been corrected.

3. Experimental results and discussion

The measurements were performed for three silicon isotopes ^{28}Si, ^{29}Si and ^{30}Si for five α-beam energies, namely: 26.3, 26.6, 27.0, 27.6 and 28.0 MeV. In the off-line analysis elastic and inelastic transitions leading to first two excited states in all isotopes were separated in the spectra. The following transitions were observed:

for ^{28}Si	g. s. (0^+)	1.78 MeV (2^+)	4.61 MeV (4^+)
for ^{29}Si	g. s. ($1/2^+$)	1.27 MeV ($3/2^+$)	2.03 MeV ($5/2^+$)
for ^{30}Si	g. s. (0^+)	2.24 MeV (2^+)	3.50 MeV (2^+)

The measured angular distributions for all incident energies and all transitions are presented in Fig. 4 (^{28}Si), Fig. 5 (^{29}Si) and Fig. 6 (^{30}Si).

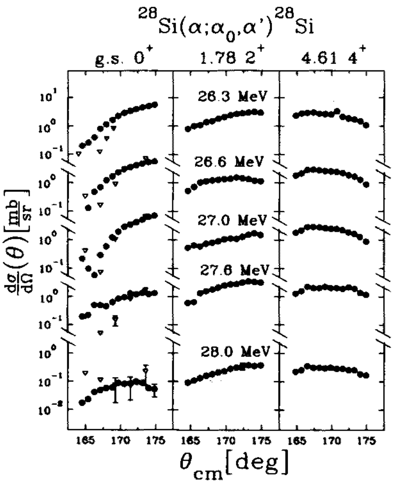

Fig.4.

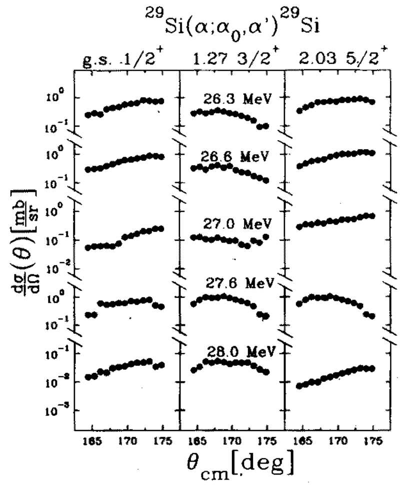

Fig.5.

Fig. 4. Experimental angular distributions of α particles scattered to the ground state (0^+) and two excited states: 1.78 MeV (2^+) and 4.61 MeV (4^+) in ^{28}Si. Open triangles - data points taken from [18].

Fig. 5. Experimental angular distributions of α particles scattered to the ground state ($1/2^+$) and two excited states: 1.27 MeV ($3/2^+$) and 2.03 MeV ($5/2^+$) in ^{29}Si.

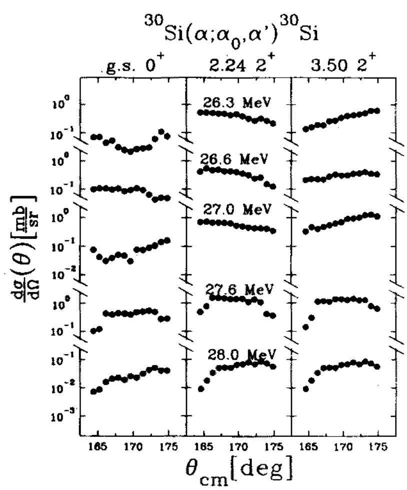

Fig. 6. Experimental angular distributions of α particles scattered to the ground state (0^+) and two excited states: 2.24 MeV (2^+) and 3.50 MeV (2^+) in ^{30}Si.

For $\alpha + {}^{28}$Si case our previous measurement data points [15] are also shown. The agreement between both experiments is good.

Unfortunately a small angular range covered in this experiment makes a quantitive optical model analysis rather impracticable. However, some qualitative conclusions can be drawn. For the first three incident energies $\alpha + {}^{28}$Si elastic angular distributions clearly go up with increasing angles. This tendency can be seen also in the case of $\alpha + {}^{29}$Si scattering, however the slope is much smaller. For the $\alpha + {}^{30}$Si case the tendency seems to be opposite. The elastic angular distributions fall down or stay almost constant. On the other hand for the two highest incident energies the shape of the angular distribution remains the same for all three isotopes.

Comparing for a given isotope, the cross sections corresponding to the inelastic transitions with the elastic one we notice that their absolute magnitudes are close to each other, *i.e.* these states are strongly excited via common (possibly collective) mechanism. This observation remains valid for all incident energies.

4. Conclusions

In Fig. 7 we compare ground state excitation functions for all three isotopes taken at $\theta_{lab} = 174°$ with $\alpha + {}^{28}$Si elastic excitation function measured by Czabański *et al.* [11] at $\theta_{lab} = 179°$. As can be seen from this figure the excitation functions for $\alpha + {}^{29}$Si and $\alpha + {}^{30}$Si scattering exhibit an exponential fall-off for highest energies, similar as for $\alpha + {}^{28}$Si case.

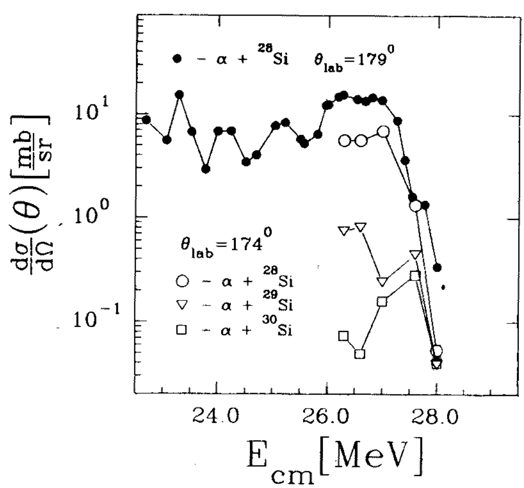

Fig. 7. Experimental elastic excitation functions for $\alpha + {}^{28,29,30}$Si systems measured at $\theta_{lab} = 174°$. Full circles — data points taken from [11]. Lines are drawn to guide the eye.

Energy integrated cross sections for $\theta_{lab} = 174°$ yield the ratios 28:3:1. This clearly shows (at least for the energy range investigated) a strong decrease of back angle cross sections with increasing neutron number in silicon isotopes.

This behavior suggests a similar explanation of the ALAS phenomenon both in the Si + α and Ca + α systems. Large back scattering cross section for doubly magic ^{40}Ca nucleus or doubly closed subshell $1d_{5/2}$ in the ^{28}Si nucleus is damped by increasing surface absorption of alpha particles due to the presence of $1f_{7/2}$ neutrons in case of calcium isotopes or $2s_{1/2}$ neutrons in case of silicon isotopes. In order to prove this conjecture more detailed studies of the full angular distributions for the elastic scattering of alpha particles on Si isotopes and ^{27}Al (analog to ^{39}K case [3]) are advisable.

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