l-DEPENDENT RESONANCE ABSORPTION IN THE OPTICAL MODEL DESCRIPTION OF ALPHA PARTICLE ELASTIC SCATTERING

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Alpha particle scattering from ^{28}Si has been studied at five bombarding energies from 23.5 to 28.5 MeV. l-dependent resonance absorption has been introduced to the optical model analysis of ^{28}Si (α, α) ^{28}Si reaction.

1. *Introduction*

The interaction of alpha particles with atomic nuclei is a useful tool for the investigation of the reaction mechanism and the structure of nucleus. Many experiments concerning the elastic scattering of alpha particles on atomic nuclei show some phenomena which are not fully understood [1–3]. Earlier investigations of the elastic alpha particle scattering from ^{12}C [4, 5], ^{16}O [4, 6], ^{20}Ne [8], ^{24}Mg [7, 8], ^{28}Si [9, 10] and ^{40}Ca [11–13] have revealed a strong energy dependence of the backward cross-section. The confrontation of theoretical predictions with the experiments shows that for these nuclei it is rather difficult to obtain good optical model fits to the elastic differential cross-sections in the full range of the scattering angles.

2. *Experimental results*

The experiment was carried out with the alpha particle beam of the 120 cm cyclotron of the Institute of Nuclear Physics in Cracow. A general description of the experimental arrangement was included in earlier papers [13, 14]. The differential cross-sections of elastically scattered alpha particles were measured in the angular range from about 25° to 177.5° at 2.5° intervals (in the lab system) and at 179° (lab). The alpha particle bombarding energy varied from 23.5 to 28.5 MeV. Numerical results including relative errors of individual measurements are available in Report No 740/PL INP Cracow [15]. The experimental angular distributions for each energy are presented in Fig. 1.

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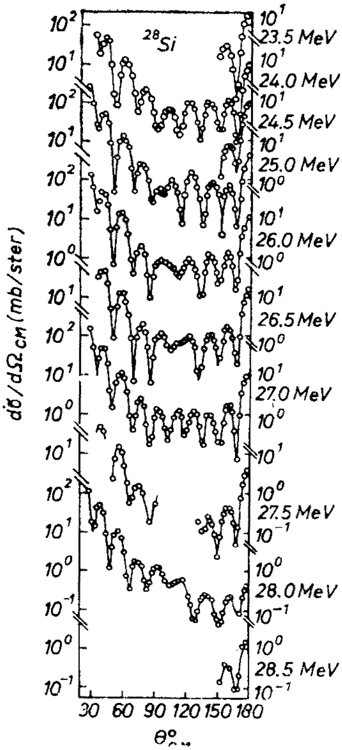

Fig. 1. Angular distributions of elastically scattered alpha particles from ^{28}Si in the energy range from 23.5 to 28.5 MeV

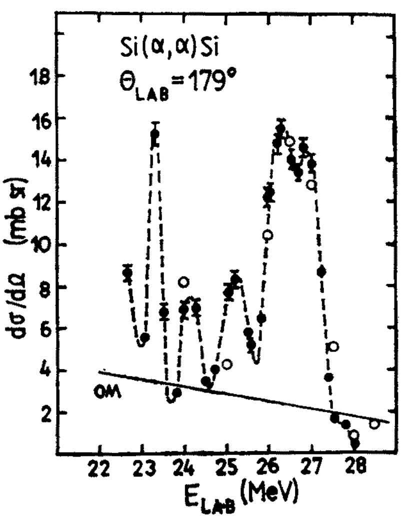

Fig. 2. Excitation functions for the elastic scattering of alpha particles from ^{28}Si, full circles — data taken from Ref. [16], open circles — data taken from Ref. [15]

It has been shown [15, 16] that the excitation functions for the elastic scattering of alpha particles have a rich structure for extremally backward angles ($\theta_{lab} = 179°$). The experimental results taken from [15] and [16] are presented together in Fig. 2. It is interesting to note that the cross-section integrated over the region from 150° to 179° has also a structure, while this does not occur if the integration is performed over angles from 30° to 60° (Fig. 3).

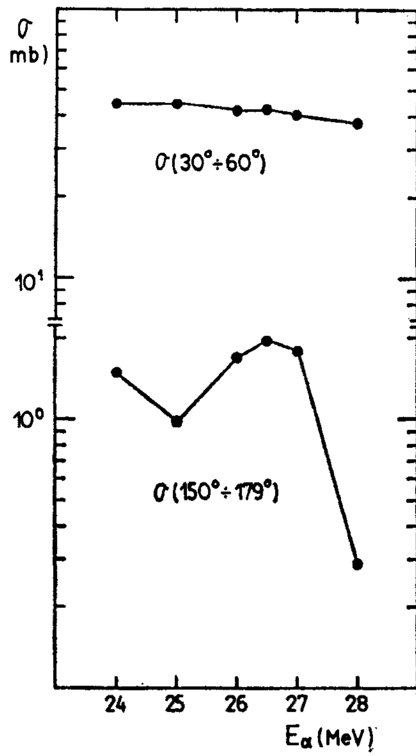

Fig. 3. Comparison of the energy dependence of the integrated cross-section in the angular regions from 30° to 60° and from 150° to 179°

3. *Analysis*

The standard optical model

In order to describe the angular distributions of alpha particle scattering on ^{28}Si a four parameter optical model analysis with the potential of the form

$$V(r) = -(U+iW)\left[1+\exp\left(\frac{r-R}{a}\right)\right]^{-1} + V_{Coul}(r) \tag{1}$$

was performed [17].

It was shown [17] that among several parameter sets found only those with a real depth near 50 MeV could be accepted. The geometrical parameters were fixed ($r = 1.699$ fm and $a = 0.505$ fm) and the following linear functions gave the energy dependence of the real and imaginary depth of the optical model potential [17]:

$$U(E_\alpha) = 0.067E_\alpha - 52.485 \text{ [MeV]},$$

$$W(E_\alpha) = -0.351E_\alpha + 0.058 \text{ [MeV]}, \tag{2}$$

where E_α is the laboratory energy (in MeV) of the incoming alpha particles.

With the parameters averaged above the description of the angular distributions was good enough up to 60° (in CM system) for each of the energies analysed. In this angular region the influence of resonance effects was expected to be less pronounced. For the backward angles ($\theta \geqslant 90°$ CM) the theoretical differential cross-section lies below the experimental points. This is to be seen in Fig. 2, where the full line indicates the optical model calculations.

Optical model with the l-dependent resonant absorption

The difficulties of the description of the angular distributions for the elastic alpha particle scattering on ^{28}Si with the standard optical model are probably connected with the significant contribution of resonance processes to the elastic scattering. This is confirmed by the existing rich structure of the excitation function (see Fig. 2).

An attempt was made to fit the elastic angular distributions by modifying the η_l coefficient for one partial wave only while the η_l coefficients for other partial waves were

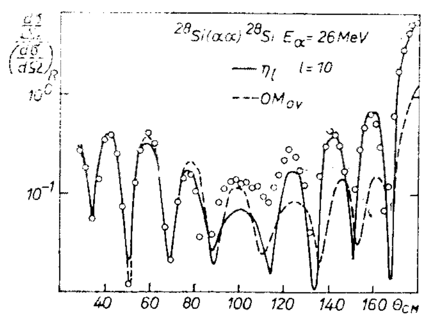

Fig. 4. The ratio of the observed to the Rutherford cross-section for the elastic scattering of 26 MeV alpha particles on ^{28}Si. The optical model fit is indicated by the dotted line. The solid line indicates optical model fit with the modified $\eta_{l=10}$ coefficient

obtained with the optical model parameters described in the previous section. The improvement of the fits obtained was significant for every incident alpha particle energy. As an example, the result of this procedure for 26 MeV alpha particles which corresponds to the modification of the η_{10} coefficient is shown in Fig. 4.

These facts may indicate the presence of resonance phenomena which seem to be closely connected with the alpha particle orbital angular momentum.

In order to take into account explicitly the resonant part of the alpha particle scattering in the optical model potential we modified the imaginary part W of this potential. It appeared that a good description of the resonance dependence of the optical model potential can be given by the following expression with the l-dependent absorption part:

$$W(r, l) = -Uf(r) - iWf(r)G(l), \tag{3}$$

where

$$f(r) = \left[1 + \exp\left(\frac{r-R}{a}\right)\right]^{-1}$$

and

$$G(l) = 1 - A_l \exp\left[-\left(\frac{l-l_c}{\Delta l}\right)^2\right]. \tag{3a}$$

The l_c and Δl in Eq. (3a) are the resonant angular momentum parameter and the diffuseness of the orbital angular momentum, respectively. The parameter A_l characterises the modification of the absorptive part of the potential ($0 \leqslant A_l \leqslant 1$).

The calculations were performed with the optical model code MAGALI [18] in which modifications according to formulas [3] and (3a) were introduced [19].

The ^{28}Si (α, α) elastic scattering data for the energies $E_\alpha = 24$, 25, 26, 26.5 and 27 MeV were analysed as follows. Starting from the average optical model parameters U, W (Eq. (2)) and fixed r_0 and a, we decreased only the imaginary depth W of the optical potential (3) for some orbital angular momentum l_c. The quality of fits was determined by the usual χ^2 criterion:

$$\chi^2 = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{\sigma_{\text{exp}}(\theta_i) - \sigma_{\text{th}}(\theta_i)}{\Delta\sigma_{\text{exp}}(\theta_i)}\right)^2 = \min, \tag{4}$$

where N is the number of data points, $\sigma_{\text{exp}}(\theta_i)$ and $\sigma_{\text{th}}(\theta_i)$ are the measured and calculated differential cross-sections, respectively, and $\Delta\sigma_{\text{exp}}(\theta_i)$ are the errors of the experimental cross-sections. During the calculations the diffuseness of the orbital angular momentum parameter Δl was fixed as $\Delta l = 0.3$.

TABLE I

Calculated parameters of the l-dependent absorption part of the optical model potential

E [MeV]	l_1	A_1	l_2	A_2	Δl
24.0	9	0.05	10	0.10	0.3
25.0	9	0.10	10	0.10	0.3
26.0	10	0.25	—	—	0.3
26.5	10	0.35	—	—	0.3
27.0	10	0.30	11	0.30	0.3

The quantities l_c and A_l were treated as free parameters and were adjusted simultaneously with the optical model parameters. It was found that for all the energies the best agreement was obtained by modifying the imaginary depth W for one or perhaps two partial waves only. The results are listed in Table I and the angular distributions with the l-dependent resonant term in the optical potential are presented in Fig. 5.

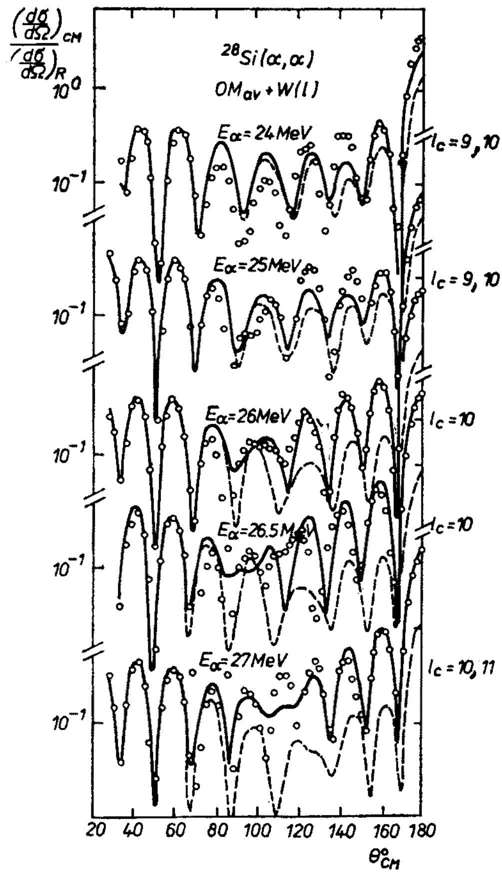

Fig. 5. The measured and calculated angular distributions of elastically scattered alpha particles from ^{28}Si. Dotted curve obtained with the averaged standard optical potential, solid curve with the l-dependent optical potential

4. Discussion and conclusions

l-dependent absorption has recently been included in the analysis of heavy ion and α particle scattering data [20–22]. The potential with the l-dependent imaginary part given by:

$$W(r, l) = W\left[1+\exp\left(\frac{r-R}{a}\right)\right]^{-1} F(l) \qquad (5)$$

has been used, where $W(r)$ is modified by a smooth angular momentum factor of the form

$$F(l) = \left[1+\exp\left(\frac{l-l_c}{\Delta l}\right)\right]^{-1}. \tag{6}$$

The factor (6) reduces the imaginary strength as l increases, which can be expected from the conservation of energy and momentum in the exit channels.

Consequently, the absorption for high partial waves is less than that for lower ones, so that the particles are scattered back into the elastic channel.

This modification (6) does not include the resonances observed in the elastic channel. By the introduction of l-dependent resonance absorption (3a) it is possible to introduce the resonance phenomenon into the optical model. This gives a significant improvement of the fits and provides a simple way of estimating the resonant angular momentum l_c and energy E_c.

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