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Study of the elastic scattering of ^{20}Ne on ^{16}O nuclei at energy below the Coulomb barrier

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Abstract. The angular distribution of the elastic scattering of ^{20}Ne on ^{16}O nuclei was measured at the cyclotron DC-60 (Astana, Kazakhstan) at the energy of E_{lab} = 30 MeV. The measurements were performed in the angular range of 35^o-165^o in the center mass system using ΔE-E method. The gallium arsenide detector was used as E detector which has the high radiation resistance and the high energy resolution (the estimated resolution for the energy 5.499 MeV of the alpha source was 22.3 keV). The growth of the scattering cross section in the backward hemisphere is not observed in the angular distributions of the elastic scattering. The calculations based on the standard optical model were sufficient to describe the behavior of the differential cross section in the full angular range.

Key words. The elastic scattering, the optical model of the nuclei, the alpha-cluster transfer mechanism, the folding model.

1. Introduction

The characteristic feature of the elastic scattering of neon on oxygen nuclei at energies above the Coulomb barrier in Gao et al. (1998); Stock et al. (1976); Kondo et al. (1983) is an abnormal increase in the cross sections at the backward angles. The description of the cross section in the backward hemisphere at the energy of 50 MeV (Stock et al. 1976) was achieved with taking into account the contribution of the elastic transfer mechanism of the alpha-cluster. During the analyzing of the revised data at this energy (Burtebayev et al. 2015) the modified optical potential with a deep real part was used to describe the rise of the reaction cross sections at the backward angular direction. The significant improvement in the description of the differential cross sections of the elastic scattering in the full angular range obtained in the framework of the coupled reaction channels method with taking into account the contribution of the elastic transfer of the alpha cluster to the scattering cross sections (Burtebayev et al. 2016). In the present work the elastic scattering of ^{20}Ne on ^{16}O nuclei was investigated at the energy of E_{lab} = 30 MeV in order to clarify the possible contribution of the elastic transfer mechanism to the scattering process with decreasing the projectile energy.

2. Experimental details

The experiment was performed using the accelerated ^{20}Ne ions extracted from the cyclotron DC-60 INP (Astana, Kazakhstan). The beam current was measured using a Faraday Cup and to be nearly 45 nA during the experiment. The energy of ^{20}Ne was 30 MeV. The self-supporting target $Al_2 O_3$ with thickness of 30 μg/cm^{-2} was used. The target thicknesses were determined at the proton beam of the UKP-2 accelerator (Almaty, Kazakhstan) by measuring the yield of γ-rays (E_{gamma} = 1779 keV) depending on the protons energy loss during the passage through the target. For this purpose the narrow resonance with E_R = 992 keV in the reaction ^{27}Al(p, γ)^{28}Si was used. Such method allows determining the thicknesses of the films in the interval of $(10 \div 100)\mu$g/cm^{-2} with the accuracy not worse than 5%.

The angular distribution of the elastic scattering ^{20}Ne was measured in the angular range 35^o-165^o in the center of mass system with an increment $\Delta\,\theta = 2^o$. The dead time of the registration system was monitored and kept as constant as possible by changing the spectrometer entrance slits and/or the beam intensity. The Δ E-E method was used for the registration and identification of the products of the nuclear reactions, which based on the simultaneous measurement of the specific energy losses (ΔE/dx) and the total kinetic energy (E) of the charged particles. The detectors were located at a distance of 24 cm from the target and moved in the angular range from 12^o to 75^o in the laboratory system. The thickness of Δ E detector was 8 μ (ORTEC Company) and the E detector had the thickness of 40 μ. The E detector was based on high-purity VPE (Vapor-Phase Epitaxy) GaAs layers. Gallium arsenide detector was manufactured in the IETP of al-Farabi Kazakh National University. The special features of this detector are the high radiation resistance and the high energy resolution (the estimated resolution for the energy 5.499 MeV of the alpha source was 22.3 keV at the width of the generator peak 6.0 keV). The simultaneous measurement of E and Δ E/dx of each particle occupies a locus in the coordinate space (Δ E, E), which allows to select the right type of the outgoing particles. Fig. 1 shows the typical Δ E-E-distribution of the charged particles. The final normalization of the absolute cross sections was determined by the comparison of the measurements at the forward angles, where Rutherford scattering dominates, with the optical model predictions which in this angular region are weakly dependent on the potential parameters.

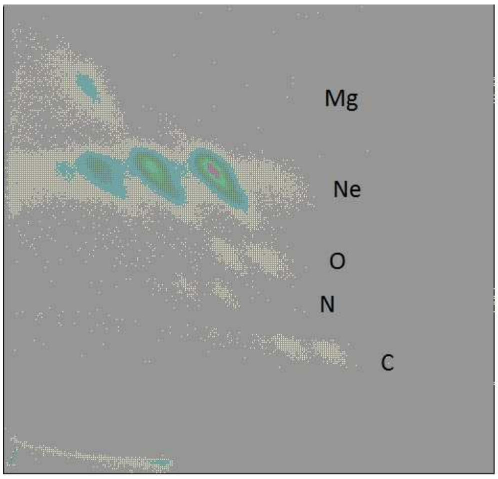

Fig. 1. Δ E-E-distribution of the charged particles

3. Data analysis

The most developed method of the extracting information about the potentials of the interaction of the particles with the atomic nuclei is the phenomenological analysis of the experimental data on the elastic scattering which based on the optical model. The optical model takes into account the effect of the inelastic channels by phenomenological introduction of the absorbing imaginary part of the potential between the colliding nuclei. In this approach, the problem of the scattering in a many-particle system is reduced to a simple process of the scattering in the field of the complex optical

potential U(r). The shape and the size of this potential are determined by the optimizing of their parameters when describing the corresponding experimental data.

Technically, this procedure is associated with the solution of the Schrodinger equation:

$$\Delta\Psi + \frac{2}{\mu}[E + U(r)]\Psi = 0 \tag{1}$$

Here $\mu = m\,A_p * A_t/(A_p + A_t)$ - the reduced mass of the colliding nuclei; A_p and A_t - the masses of the projectile and the target nucleus; m - the mass of a nucleon; E - kinetic energy of the relative motion in the c. m. s.

The experimental data of the elastic scattering were analyzed within the framework of the optical model. For all calculations, the Woods-Saxon form factor was used for both the real and imaginary parts:

$$U(r) = V + iW \tag{2}$$

$$V = V_0[1 + exp(r - R_r)/a_r]^{-1} \tag{3}$$

$$W = W_0[1 + exp(r - R_i)/a_i]^{-1} \tag{4}$$

where V_0, W_0, a_r, a_i, R_r and R_i being the depth, diffuseness and radii of the real and imaginary potentials, respectively. The radii are expressed in terms of the mass numbers A_p and A_t of the nuclei involved given by:

$$R = r_0(A_p^{1/3} + A_t^{1/3}) \tag{5}$$

The automatically look-up of the optimal optical parameters was carried out using the SPI-GENOA program by means of the minimization of the χ^2/N ? value:

$$\chi^2 = \frac{1}{N}\sum_{i=1}^{N}[((\sigma_i)_T - (\sigma_i)_E)/(\Delta\sigma_i)_E]^2 \tag{6}$$

where $(\sigma_i)_T$ and $(\sigma_i)_E$ - the theoretically calculated and the experimental values of differential cross sections at a given angle θ; $\Delta(\sigma_i)_E$ - the experimental error; N - the number of the measured points. In Fig. 2, the dashed line represents the cross sections calculated using the OM with the potentials taken from the Table 1. As can be seen from the Fig. 2, the theoretical cross sections describe well the experimental data in the complete angular range for the energy E = 1.5 MeV/ nucleon.

The folding model (FM) is the semi-microscopic model (Sing et al. 1975) which determines the potential interaction of the complex particles and nuclei based on the information of the relatively well-known the nucleon-nucleon forces and the density distribution of the nuclear matter. In contrast to the phenomenological approach, the potential and form factors of the inelastic transitions in the framework of the folding model do not contain free parameters, and this gives hope for a significant reduction of the potential ambiguities of the values extracted from the analysis of the elastic scattering calculated in the framework of the OM. In this work the imaginary part was taken in the form of the Woods-Saxon potential and included only the volume type of the absorption. In this case, only free parameter was the normalization coefficient N for the real part of the potential. The optimal values of the parameters of the folding model obtained from the fitting of the calculated values with the experimental cross sections are included in the Table 1.

The calculation was carried out using the Korobov integral, implemented to the standard MIKOR and FRESCO programs. In Fig. 2, the solid line represents the cross sections calculated within the framework of the folding model. It is seen that the cross sections calculated by folding model correlate with the cross sections calculated using the phenomenological model and with the experimental data.

4. Conclusions

The experiment on the elastic scattering of ^{20}Ne ions on ^{16}O nuclei was performed at energy E = 1.5 MeV/nuc. The measurements

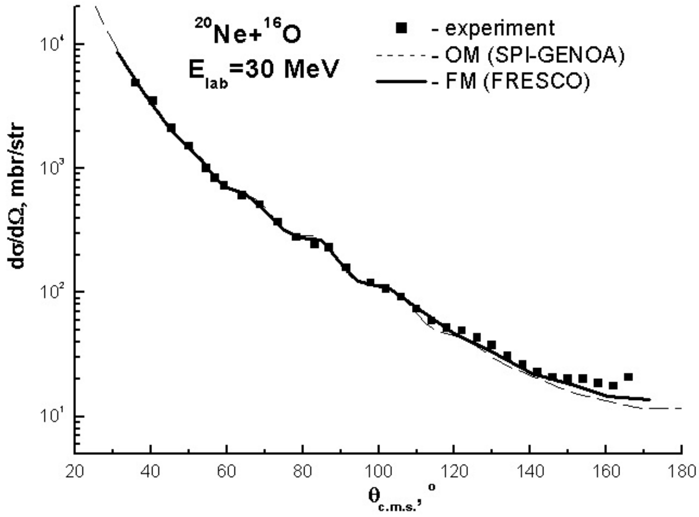

Fig. 2. The comparison of the experimental and theoretical differential cross sections of the elastic scattering of ^{20}Ne on ^{16}O at the energy of 1.5 MeV/nuc. Squares - the experimental data; the dashed line - cross sections calculated using the phenomenological potential from Table 1; the solid line - cross sections calculated using FM.

Table 1. The optimal parameters of the phenomenological (OPP) and folding (FM) potentials used in the optical model calculations

Pot.	$E(MeV)$	V_0(MeV)	r_0(fm)	a_0(fm)	W_0(MeV)	r_w(fm)	a_w(fm)	N_r
OPP	30	110.0	1.2	0.49	20.00	1.2	0.32	
FM					20.00	1.2	0.32	1.0

were conducted in the angular range of 35^o-165^o in the center of mass system using ΔE-E method. The gallium arsenide detector was used as E detector which has the high radiation resistance and the high energy resolution (the estimated resolution for the energy 5.499 MeV of the alpha source was 22.3 keV). The differential cross sections up to 180^o gradually decrease. The parameters of the potentials were obtained from the analysis of the experimental data in the framework of the optical model. In this case the phenomenological and folding potentials were used. It is shown that the folding and phenomenological potentials equally well describe the experimental data.

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