ELASTIC SCATTERING OF ^{15}N IONS BY ^{16}O AT THE ENERGY 11.59 MeV*

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The main purpose of this work is to find optimal optical parameters and to investigate the transfer mechanism at low energy, close to the Coulomb barrier energy for $^{15}\mathrm{N}+{}^{16}\mathrm{O}$ nuclear systems. Angular distributions were measured at the energy $E_{\mathrm{cm}} = 11.59$ MeV using stable ^{15}N beams and target Al_2O_3 with thickness 30 μg/cm^2. The beam of ^{15}N was accelerated on cyclotron DC-60 (INP, Astana). Registration and identification of charged particles was conducted by ΔE–E method. The data were analyzed within the optical model (OM) and coupled reaction channels (CRC) method. The CRC calculation was used by the program code Fresco [I.J. Thompson, *Comput. Phys. Rep.* **7**, 167 (1988)].

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1. Introduction

Heavy-ion reactions are an important field in the nuclear physics. The study of the interaction between the heavy-ions with nuclei is a main subject in the heavy ion physics. The optical model, in which the highly complicated nucleus–nucleus interaction is replaced by a complex two-body effective potential, plays a central role in the description of nucleus–nucleus scattering [1]. In nuclear physics, it is often useful to assume the presence of clusters of nucleons in the nucleus, and the participation of such clusters in nuclear reaction. For convenience this is referred to as a proton particle, although its properties inside the nucleus may not be the same as that of a free proton particle, owing to the action of the surrounding nucleons. The emission of proton particles from nuclei, and the pickup of proton particles

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by other nuclei in some reactions do not imply by themselves the presence of proton particles in the nucleus because it is conceivable that the proton particle is formed at the moment of emission, as it is indeed postulated by the coalescence model [2]. So, reaction such as $^{15}\mathrm{N} + {}^{16}\mathrm{O}$ is a good example for studying the proton transfer mechanism because of the possibility for the existence of proton particles at the surface of $^{16}\mathrm{O}$, especially at low energies close to the Coulomb barrier energy. The concept of clustering is widely used in physics, and indeed in the whole science.

2. Experimental method

The experiments were performed using an $^{15}\mathrm{N}$ beam accelerated using the cyclotron DC-60 INP located in Astana, Kazakhstan. The $^{15}\mathrm{N}$ beam was accelerated to energies 1.5 MeV/nucleon and then directed to $\mathrm{Al_2O_3}$ target of thickness 30 μg/cm^2. The angular distribution was measured for $^{15}\mathrm{N} + {}^{16}\mathrm{O}$ nuclear system at energy 11.59 MeV in the 28°–170° range of angles in the center-of-mass system with an increment 2°. ΔE–E counter telescopes were used for particle identification. The thickness of ΔE detector is 8 μm and E detector is 200 μm. The scattered beam particles were detected in the forward angular range. As their energy was too small at backward angles, the angular region from 90° to 170° was covered by measuring the recoiling nuclei in the forward direction. To find the differential cross section, it is necessary to consider changes in the effective thickness of the target which depends on the relative location of the target $x_{\mathrm{eff}} = x/\cos(\theta_{\mathrm{lab}})$ [3], as shown in Fig. 1.

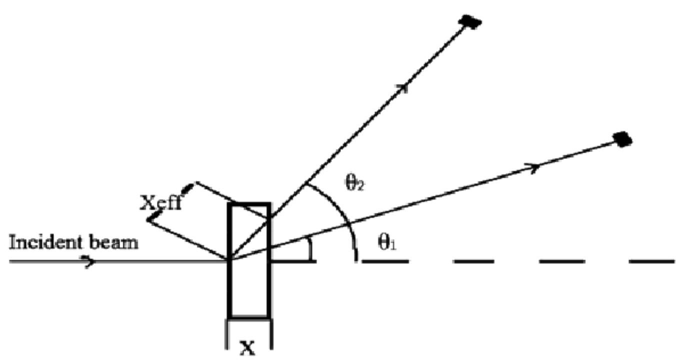

Fig. 1. Geometry for measuring the scattering process by a thin foil.

3. Results

For the reaction $^{16}\mathrm{O}(^{15}\mathrm{N},{}^{16}\mathrm{O})^{15}\mathrm{N}$, an important process affecting the elastic scattering cross section at large angles is the mechanism of proton transfer from the $^{16}\mathrm{O}$ target nucleus to the $^{15}\mathrm{N}$ projectile nucleus, forming the nucleus in the ground state. This process can be described in the method of distorted waves. Then, taking into account the transfer of the cluster, we can write down for the reaction of the elastic scattering $^{16}\mathrm{O}(^{15}\mathrm{N},^{16}\mathrm{O})^{15}\mathrm{N}$

$$\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}\Omega} = \left[f_{\mathrm{el}}(\theta) + e^{i\alpha} S f_{\mathrm{DWBA}}(\pi - \theta)\right]^2 , \qquad (1)$$

where $f_{\mathrm{el}}(\theta)$ — elastic scattering amplitude, $f_{\mathrm{DWBA}}(\pi - \theta)$ — amplitude calculated in the distorted-wave method, $S = -1.46$ (normalization factor) [4], parameter $\alpha = \pi$ (coherence of amplitudes).

The optimal optical potential parameters from Sfresco code which have been used as input parameters in Fresco code for ^{15}N (projectile) +^{16}O (target) and ^{16}O (projectile) +^{15}N (target) nuclear systems are shown in Table I.

TABLE I

Optical model parameters of the $^{15}\mathrm{N} + {}^{16}\mathrm{O}$ potential.

System	E_{cm} [MeV]	V [MeV]	W [MeV]	a_v [fm]	r_v [fm]	a_w [fm]	r_w [fm]
$^{15}\mathrm{N} + {}^{16}\mathrm{O}$	11.59	105.7	9.7	0.526	1.16	0.526	1.16

The angular distribution of the measured $^{15}\mathrm{N} + {}^{16}\mathrm{O}$ elastic scattering at the energy $E_{\mathrm{lab}}(^{15}\mathrm{N}) = 22.5$ MeV is presented in Fig. 2 by black dots. First, the data were analyzed within the OM. Next, the deduced optimum potential

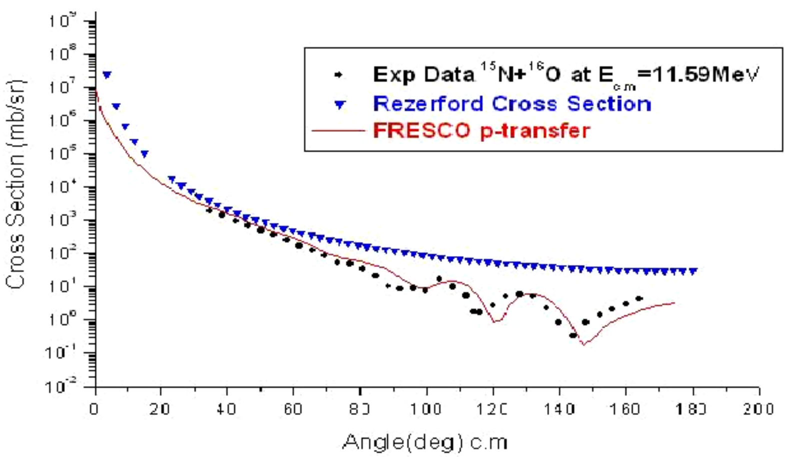

Fig. 2. The angular distribution for the elastic scattering of ^{15}N on ^{16}O at c.m. energy of 11.59 MeV. Dots represent experimental data; solid line presents theoretical cross sections including the optical model and one-step elastic transfer contributions; triangles represent the Coulomb cross section.

parameters V, W, r_v, a_v, r_w, a_w were optimized in the CRC calculations. The $^{15}\mathrm{N} + {}^{16}\mathrm{O}$ potential parameters obtained in the CRC analysis of the data are listed in Table I. The calculation using CRC method describes well all the range of angles (Fig. 2, solid line).

4. Summary

In this paper, the proton transfer mechanism has been studied in $^{16}\mathrm{O}(^{15}\mathrm{N}, {}^{16}\mathrm{O})^{15}\mathrm{N}$ nuclear system at energy $E_{\mathrm{cm}} = 11.59$ MeV, and optical potential parameters were found. Two approaches were used in data analysis: the optical model code (Sfresco) and the CRC (Fresco) code to account for the transfer mechanism. The optical model code Sfresco can effectively fit the experimental data at the first hemisphere (angles lower than 90°), while the (Fresco) CRC code can be used for fitting the experimental data at all angles. From our study, it is clear that proton particle can exist in the surface part of $^{16}\mathrm{O}$ nucleus especially at low energies close to the Coulomb barrier and hence, $^{16}\mathrm{O}$ can be treated as $^{15}\mathrm{N} + p$.

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