Analysis of elastic scattering $^{14}$N on $^{16}$O at energies near coulomb barrier in frame of optical model.


Abstract—The aim of this work is to analyze the elastic scattering of $^{14}$N on $^{16}$O at low energies near coulomb barrier in framework of the optical model using SPI-GENOA code.

For comparison of results the experimental data of the elastic scattering of $^{14}$N on $^{16}$O at the energies 1.5 MeV/n, 1.75 MeV/n were used. Experimental data were calibrated and analyzed within ROOT. The real and imaginary parts of optical potential were found and compared with systematic data.

Keywords—heavy ion elastic scattering at low energies, nuclear structure, optical model, SPI-GENOA.

I. INTRODUCTION

The scattering of two nuclei the density distributions of the two objects overlap and exchange of nucleons, clusters can take place which leads back to the incident channel and thus to coherent contributions to the potential scattering. The rearrangement of the outer nucleons in the scattering can involve exchange in both directions, the probabilities of the different amplitudes will depend on the structure of the colliding nuclei. It has recently been understood there is not enough negligible effect of transfer in displaying the oscillatory structure observed in the experimental data measured at relatively low energies close to the Coulomb barrier energy for $^{14}$N+$^{12}$C nuclear system, which testifies to a low clustering in the nitrogen nucleus.[1] An elastic scattering of $^{14}$N on $^{16}$O target nuclei at low energies preferred to examine if there will be any significant increase in differential cross sections at backward angles due to deuteron transfer.

In the work [3] the differential cross section for mentioned system was calculated in the frame of optical model with spin-orbit interaction and more or less in good agreement at backward angles with the experimental data above the Coulomb barrier. All the experimental data was obtained from [2] and [3] where compared with our experimental data. The optical model code SPI-GENOA could be used effectively for fitting the experimental data with the theoretical predictions nearly up to angle 90°, where the differential cross section decreases steadily with increasing the scattering angle.

II. EXPERIMENTAL DETAILS

The experiments were performed using an $^{14}$N beam accelerated in the cyclotron DC-60 INP NNC located in Astana, Kazakhstan, which could accelerate the elements from Lithium to Xenon with an energy range from 0.35 MeV/n to 1.75 MeV/n. Beam current was measured using a Faraday Cup to be nearly 30 nA during these experiments. The dead time was monitored and kept as constant as possible by changing the spectrometer entrance slits and/or the beam intensity. The $^{14}$N beam was accelerated up to energies 17.5, 21 and 24.5 MeV and then directed to $^{27}$Al-$^{16}$O target of thickness 20 μg/cm2. The choice of a light oxide such as $^{27}$Al as the target has a number of advantages since it allows relatively good spectral separation between the $^{14}$N nuclei scattered by $^{27}$Al and $^{16}$O and also, the forward focusing of the yields from $^{27}$Al suppresses their contribution at larger angles. The thickness of target was determined using the resonance chamber in the linear accelerator UKP-2-1 INP Almaty–Kazakhstan. Thus, angular distributions were measured for $^{14}$N ($^{16}$O, $^{16}$O) $^{14}$N nuclear system at energies 17.5, 21 and 24.5 MeV in laboratory system, in the 20°–90° range of angles in the centre of mass system with an increment $\Delta \theta = 2°$. To register the scattered $^{14}$N beam, a surface-barrier silicon detector from the company ORTEC was used (diameter of the sensitive area of 8 mm, thickness - 0.2 mm). The detector was located at a distance of 24 cm from the scattering region and had the opportunity to move in the angular range from 100 to 750 in the laboratory frame. The energy resolution of the detector was 250-300 keV, which is mainly determined by the energy spread of the primary beam. The nominal maximum voltage which could be applied on the detector is 20 volts but, during the
experiment it was raised up to 30 volt. The $^{14}$N beam were passed through three collimators and focused on the target to a spot diameter of $\approx 3.0$ mm. In order to minimize the evaporation of the target, the beam current was limited to $50 \text{nA}$. Spectrum analysis has been performed using the program MAESTRO [6]. Fig. 1 shows for $^{14}$N($^{16}$O, $^{16}$O)$^{14}$N elastic scattering the obtained spectrum at angle $50^\circ$ and at energy $17.5 \text{ MeV}$.

Fig. 1 Spectrum for $^{16}$O($^{14}$N, $^{14}$N)$^{16}$O elastic scattering at angle $50^\circ$ and at energy $24.5 \text{ MeV}$.

Formula by which the differential cross section from the experiment could be calculated is shown by Eq.(1):

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{lab}} = \frac{N}{N_0 n_s \Delta \Omega} \tag{1}$$

Where $N$ – the number of particles registered by the detector, $N_0$ – total number of particles falling on the target (linked to the value of integrator), $\Delta \Omega$ – the solid angle which could be determined from the system configuration (detector, aperture and the distance from the target to the detector), $n_s$ is the number of nuclei per unit area of the target. $n_s$ could be calculated from the expression: $n_s = x N_z / M \text{ ns}$, here $x$ is the target thickness in g/cm$^2$. By taking into account all these parameters one could calculate the differential cross section in absolute units. Actually, to find the differential cross section, it is also necessary to consider changes in the effective thickness of the target which depending on the location relative to the target $x_{\text{eff}} = x / \cos(\theta_{\text{lab}})$, as shown in Fig. 2.

Then, one can change the differential cross section from the laboratory system into the center of mass system using the following formula:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{CM}} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{lab}} \left[\frac{1 + 2 \lambda \cos(\theta_{\text{CM}}) + \lambda^2}{1 + \lambda \cos(\theta_{\text{lab}})}\right]^{\frac{3}{2}} \tag{2}$$

where $\lambda = m_p / m_t$ – the ratio of the mass of the projectile nucleus $m_p$ to the mass of the target nucleus $m_t$, $\theta_{\text{CM}}$ is the scattering angle in the center of mass system.

### III. Theoretical Analysis

#### A. Optical model analysis.

In this work the Woods-Saxon (WS) shape for the potential real part and also WS shape for the imaginary volume part of the potential had been assumed in accordance with previous phenomenological analyses of $^{14}$N+$^{16}$O nuclear systems [14-16].

Thus, the optical potential can be written as:

$$U(r) = V_c(r) - V(r) - iW_c(r). \tag{3}$$

The first term is the Coulomb potential. Since scattering is not sensitive to a specific form of the charge distribution, and therefore there is no need to consider its diffuse boundary, then the Coulomb potential was assumed to be that between two uniform charge distributions with radii consistent with electron scattering:

$$V_c(r) = \frac{Z_e Z_t e^2}{2 R_c} \left(3 - r^2 / R_c^2\right), \quad r \leq R_c \tag{4}$$

$$V_c(r) = \frac{Z_e Z_t e^2}{r}, \quad r > R_c \tag{5}$$

The real part has the following form:

$$V(r)f(r, r_v, a_v) = V_0 \left[1 + \exp \left(\frac{r - r_v}{a_v}\right)\right]^{-1}.$$  

The imaginary volume part:

$$W_c(r)f(r, r_v, a_v) = W_0 \left[1 + \exp \left(\frac{r - r_v}{a_w}\right)\right]^{-1}.$$

So, the Interaction potential can be rewritten as:
The comparisons between the experimental data and the theoretical predictions performed using both OM approaches for $^{14}\text{N}^{16}\text{O}$ nuclear system at energies 1.5 and 1.75 MeV/n are shown in Figs. 5 and 6 respectively.

The measurements were not extended behind $\approx 130^\circ$, the data in this angular range doesn’t show a significant increase in differential cross section. The agreement between the experimental and theoretical calculations is fairly good over the whole angular range using both OM analysis.

Optimal optical potential parameters for $^{14}\text{N}^{16}\text{O}$ nuclear systems are listed in Table I. The spectroscopic factors used for or calculation was given in [2] and transition data in [5].

<table>
<thead>
<tr>
<th>E_{lab} (MeV)</th>
<th>OM</th>
<th>$V_0$ (MeV)</th>
<th>$r_v$ (fm)</th>
<th>$a_v$ (fm)</th>
<th>$W_0$ (MeV)</th>
<th>$r_c$ (fm)</th>
<th>$a_s$ (fm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.1</td>
<td>WS</td>
<td>10.6</td>
<td>6.9</td>
<td>0.5</td>
<td>0.75</td>
<td>6.9</td>
<td>0.5</td>
</tr>
<tr>
<td>25</td>
<td>WS</td>
<td>17</td>
<td>1.35</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>WS</td>
<td>172.5</td>
<td>1.47</td>
<td>0.72</td>
<td>2.007</td>
<td>1.61</td>
<td>1.09</td>
</tr>
<tr>
<td>24.5</td>
<td>WS</td>
<td>161.55</td>
<td>0.67</td>
<td>1.10</td>
<td>40.37</td>
<td>0.87</td>
<td>0.95</td>
</tr>
</tbody>
</table>

* - from reference [3], † - from reference [2]. Bold - our calculations.

IV. RESULTS AND DISCUSSION

Our measured experimental data at energies 17.5, 21 and 24.5 MeV and the previously measured data for $^{14}\text{N}^{16}\text{O}$ at energies 31.4 and 25.0 MeV [2]-[4] are presented in Fig. 4.

![Fig. 4 The experimental differential cross section for $^{14}\text{N}^{16}\text{O}$ elastic scattering at different energies: 17.5, 21, and 24.5 MeV (our data), 25. ref. [5]) and 34.1 MeV from ref. [6])](image)

It is clearly shown that our data at energy 21 MeV is close to the previously measured data at 21.34 MeV which emphasize that our data was measured correctly. Although the data at energies 21.34 and 25.0 MeV were extended to large angles than those measured by us, but these data don’t show a significant increase in differential cross section at backward angles. The observed oscillatory structure at energies 31.34 and 25.0 MeV could be interpreted to be due to deuteron transfer between the interacting nuclei.
V. CONCLUSION

The angular distribution for $^{14}\text{N}$ elastically scattered on $^{16}\text{O}$ target nuclei at low energies close to Coulomb barrier energy for this nuclear system was measured to examine if there will be any significant increase in differential cross sections at backward angles due to deuteron transfer. If such transfer is well exist it means that $^{14}\text{N}$ nuclei is candidate to be clusterized nuclei.

It is clearly shown from our experimental data and the performed theoretical calculations that deuteron transfer doesn’t play a significant role in the formation of differential cross-section at backward angles. Meanwhile one can’t neglect the effect of transfer in displaying the oscillatory structure observed in the experimental data measured at relatively low energies close to the Coulomb barrier energy for $^{14}\text{N}+^{16}\text{O}$ nuclear system.

REFERENCES


