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Study of the Elastic Scattering of ^{16}O, ^{14}N and ^{12}C on the Nucleus of ^{27}Al at Different Energies near the Coulomb Barrier

N. Amangeldi, N. Burtebayev, Sh. Hamada and A. Amar

***Abstract*—** the measurement of the angular distribution for the elastic scattering of ^{16}O, ^{14}N and ^{12}C on ^{27}Al has been done at energy 1.75 MeV/nucleon. The optical potential code SPIVAL used in this work to analyze the experimental results. A good agreement between the experimental and theoretical results was obtained.

***Keywords*—**$^{27}Al(^{16}O,^{16}O)^{27}Al$, SPIVAL, $^{27}Al(^{14}N,^{14}N)^{27}Al$, $^{27}Al(^{12}C,^{12}C)^{27}Al$, Elastic Scattering, Optical Potential Codes.

I. Introduction

THE measurement of the elastic scattering is important both to provide the optical model potentials for using in the description of the non-elastic reactions and for the investigation of ion-ion interaction [1]. The aim of this work is to study the elastic scattering of ^{16}O, ^{14}N and ^{12}C on the nucleus of ^{27}Al using the cyclotron DC-60 located in Astana, Kazakhstan. The beam ions of ^{16}O, ^{14}N and ^{12}C were accelerated to energy 1.75 MeV/nucleon and then directed to the Al_2O_3 target of thickness 20 μg/cm^2, the angular distributions were measured in a wide range of angles 20-120^o in center of mass system. Data analysis was done using the optical model SPIVAL using the Woods-Saxon potential for both the real and for the imaginary parts. The elastic scattering ($^{16}O+^{27}Al$), ($^{14}N+^{27}Al$) and ($^{12}C+^{27}Al$) were analyzed in short range of energies because of the lack of the available experimental data at low energies. Good agreement was obtained between the experimental and calculated results with the appropriate potential parameters. We estimated the linear relationship between volume real and imaginary potentials with the energy which was obtained at low energies [2].

II. Experimental Method

The experiments were performed using an ^{16}O, ^{14}N and ^{12}C beams accelerated using the cyclotron DC-60 which can accelerate the elements from Lithium to Xenon with an energy range from 0.35 MeV / nucleon to 1.75 MeV / nucleon. The energy of the used ^{16}O and ^{12}C beam was 28 and 21 MeV respectively, while ^{14}N ions were accelerated to two different energies 24.5 and 21 MeV . The target Al_2O_3 of thickness 20 μg/cm^2 was used in these experiments ($^{16}O+^{27}Al$), ($^{14}N+^{27}Al$) and ($^{12}C+^{27}Al$). The angular distributions were measured in a wide range of angles 20-120^o in center of mass system with 1^o degree step. The energy resolution of the registration system was 250-300 keV, which is mainly determined by the energy spread of the primary beam.

N. Amangeldi is with the Eurasia National University, Astana, Kazakhstan. (e-mail: nur19792@mail.ru).
N. Burtebayev is with the Institute of Nuclear Physics of National Nuclear Center, Almaty, Kazakhstan. (e-mail: nburtebayev@yandex.ru).
Sh. Hamada is with Faculty of Physics, Kazakh National University, Almaty, Kazakhstan. Phone: 8707-344-7658; fax: 8707-356-99-42; (e-mail: sh.m.hamada@gmail.com).
A.Amar is with Faculty of Physics, Kazakh National University, Almaty, Kazakhstan. Phone: 8707-356-99-41; (e-mail: amar.physics@yahoo.com).

III. Optical Model Analysis of Elastic Scattering

The nucleus-nucleus interaction potential is a key ingredient in the analysis of nuclear reactions. By using the potential between nuclei we can evaluate the cross sections of different nuclear reactions. The optical model analysis of the experimental data was performed by using Wood-Saxons (WS) forms for both real and imaginary parts of the potential.

$$U(R)=V_c(R)-V\left[1+\exp(\frac{R-R_V}{a_V})\right]^{-1}-iW\left[1+\exp(\frac{R-R_W}{a_W})\right]^{-1} \quad (1)$$

The Coulomb potential was assumed to be that between two uniform charge distributions with radii consistent with electron scattering [3]. The elastic scattering of ^{12}C on ^{27}Al was analyzed at four different energies (30, 32, 35, 40 MeV) that are presented in ref. [2], in addition to our experimental results obtained at energy 21 MeV. The optical potential model code SPIVAL was used to analyze the experimental results. A good agreement between the experimental and calculated data was obtained with the best parameter fit. The Coulomb radius was fixed at 1.31 fm during the search.

IV. Results and Discussion

Parameters of the optical potential at energies (21, 30, 32, 35 and 40) are presented in table 1. Figure (1) shows comparison between the experimental data and the calculation predictions obtained using the optical potential code SPIVAL with potential parameters listed in table 1. Figure (2) shows the relationship between the real potential depth (V_0), imaginary potential depth (W_0) with energy. As expected the relations between (V), (W) and E are linear. The strength parameters in table 1 can be presented be:

$$V_0 = 46.137 - 0.54\ E, \qquad W_0 = 5.079 + 0.073E,$$

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TABLE I
OPTICAL POTENTIAL PARAMETERS FOR THE REACTION OF $^{12}C+^{27}Al$ USING SPIVAL CODE. THE * PARAMETERS WERE FIXED DURING THE SEARCH, AND $R=r_o (A_1^{1/3}+A_2^{1/3})$.

E (MeV)	V_0 (MeV)	r_r (fm)	a_r (fm)	W_0 (MeV)	r_i (fm)	a_i (fm)	r_c (fm)
21	35.76	1.3*	0.412	6.784	1.23*	0.369	1.31*
30	29.25	1.3*	0.494	6.766	1.23*	0.384	1.31*
32	27.61	1.3*	0.486	6.955	1.23*	0.375	1.31*
35	26.88	1.3*	0.453	7.679	1.23*	0.406	1.31*
40	25.67	1.3*	0.499	8.075	1.23*	0.422	1.31*

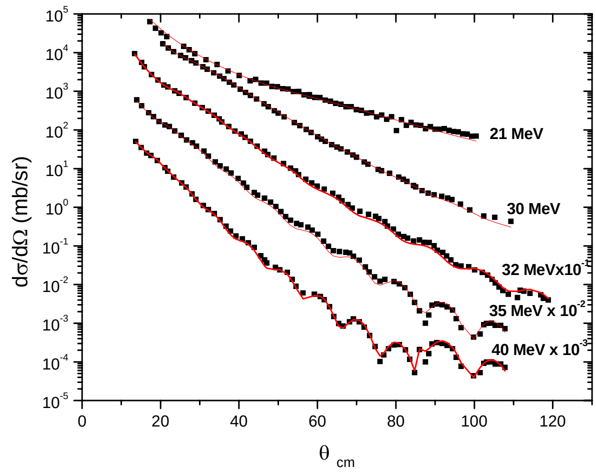

Fig. 1. The angular distribution of ^{12}C elastically scattered on ^{27}Al at energies 21, 30, 32, 35, 40 MeV respectively. The optical-model calculations are represented by the solid curves while the experimental results are represented by dotted curves.

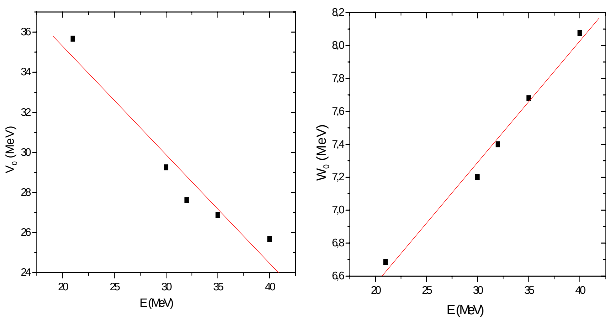

Fig. 2. (a)- shows the relationship between the real potential depth (V_0) and energy, (b)- the relationship between the imaginary potential depth (W_0) with energy (E)

The quality of the fitting of optical model calculations to the experimental data can be estimated using the χ^2- method, which is represented as

$$\chi^2 = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{\sigma_i^t(\theta)-\sigma_i^e(\theta)}{\Delta\sigma_i^e(\theta)}\right]^2 = \frac{1}{N}\sum_{i=1}^{N}\chi_i^2 \quad (2)$$

where σ^e and σ^t are the experimental and theoretical differential cross sections of the elastic scattering for i - th scattering angle, $\Delta\sigma^e$ is the error of the experimental differential cross sections at these angles, N – the number of measurements. The less the value χ^2 is, the better is the description of the experimental data in terms of the selected theoretical representation. Usually the results of calculations can be considered as wholly satisfactory if χ^2 is about 1, i.e. the deviation of the calculated values from the experimental ones is in average equal to the value of the experimental errors. The description can be considered as good if every partial χ^2 for each scattering angle is less than 1, and thus, the average χ^2 is always less than 1.

The interaction of ^{14}N beam with ^{27}Al was analyzed at the energy 52.29 MeV from ref [4], in addition to our experimental results at energies 21 and 24.5 MeV, obtained from our work in cyclotron DC-60. The optical potential model code SPIVAL was used in data analysis. A good agreement between the experimental and calculated data was obtained. Figure (4) shows the angular distribution for the interaction $^{14}N+^{27}Al$. The obtained potential parameters are shown in the table 2, the Coulomb radius was taken 1.31 fm during the search as in the case of $^{12}C+^{27}Al$.

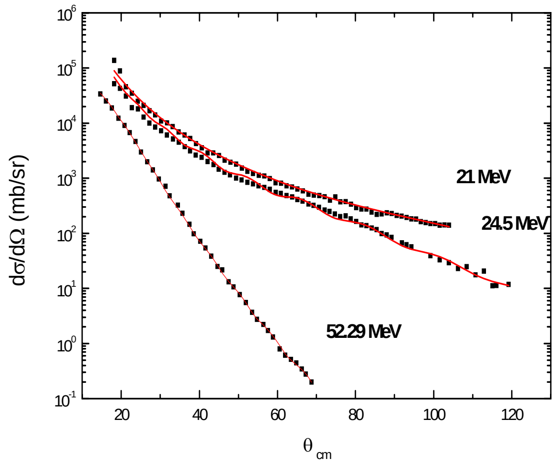

Fig. 3. The angular distribution of ^{14}N elastically scattered on ^{27}Al at energies 21, 24.5, 52.29 MeV respectively. The optical-model calculations are given by the solid curves while the experimental results are represented by dotted curves.

TABLE II
OPTICAL POTENTIAL PARAMETERS FOR THE REACTION OF $^{14}N+^{27}Al$ USING THE CODE SPIVAL, THE * PARAMETERS WERE FIXED DURING THE SEARCH, AND $R=r_o (A_1^{1/3}+A_2^{1/3})$

E (MeV)	V_0 (MeV)	r_r (fm)	a_r (fm)	W_0 (MeV)	r_i (fm)	a_i (fm)	r_c (fm)
21	70.46	1.214*	0.483	02.82	1.179*	0.997	1.31*
24.5	55.65	1.214*	0.571	8.092	1.179*	0.708	1.31*
52.29	25.85	1.214*	0.636	27.43	1.179*	0.603	1.31*

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The interaction of ^{16}O ions with ^{27}Al was analyzed at energy 28 MeV. The optical potential model code SPIVAL was used in the data analysis. A good agreement between the experimental and calculated data was obtained. The Coulomb radius was taken 1.31 fm during the search as in the case of $^{12}C+^{27}Al$ and $^{14}N+^{27}Al$ Figure (5) shows the angular distribution for the elastic scattering of ^{16}O on ^{27}Al. The obtained potential parameters are shown in table 3.

TABLE III
THE OBTAINED OPTICAL POTENTIAL PARAMETERS FOR $^{16}O+^{27}Al$ ELASTIC SCATTERING USING SPIVAL CODE

E (MeV)	V_0 (MeV)	r_r (fm)	a_r (fm)	W_0 (MeV)	r_i (fm)	a_i (fm)	r_c (fm)
28	99.49	1.12	0.75	8.55	1.18	9.85	1.31

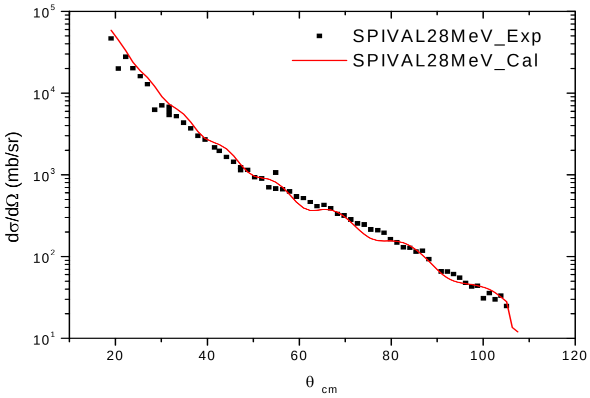

Fig. 5. The angular distribution of ^{16}O elastically scattered on ^{27}Al at the energy 28 MeV. The optical-model calculation using SPIVAL code is given by the solid curve, while the experimental results are represented by dotted curve.

V. SUMMARY

In this paper three different experiments have been done in the cyclotron DC-60 for studying the elastic scattering of ^{16}O, ^{14}N and ^{12}C on the nucleus ^{27}Al at energy 1.75 MeV/nucleon. The experimental data has been analyzed within frame work of the optical potential code SPIVAL. We managed from obtaining the optimal parameters which could describe these processes.

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