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Optical Model Analysis of Elastic Scattering of ^{6}He + ^{58}Ni Reaction

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Abstract

In the present study, the elastic scattering angular distribution of ^{6}He on ^{58}Ni is investigated at incident energies of 12.2, 16.5 and 21.7 MeV. In the calculations, three different nuclear potentials obtained with the phenomenological and the microscopic approaches based on the optical model are used. Firstly, the phenomenological Woods-Saxon potential for both real and imaginary parts of nuclear potential is considered. Secondly, the double folding potential for the real part together with an imaginary part in Woods-Saxon form is applied. Finally, the real and imaginary parts of nuclear potential are assumed as the folding potentials. The elastic scattering results of all the models are compared with the literature results as well as the experimental data. The results are in agreement with the experimental data.

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Keywords: Exotic nuclei interactions; elastic scattering; optical model; double folding model.

1. Introduction

Exotic nuclei have become one of the most interesting research fields in the nuclear physics. They have shown different features compared to the stable nuclei. For example, they have low binding energy, large rms value and different density distributions. In this sense, the ^{6}He nucleus which consists of a tightly bound core (α) and valence nucleons ($n + n$) is one of the most investigated exotic nuclei. With this goal, a lot of both theoretical and experimental studies have been carried out (AYGUN et al. 2010, 2012, 2013; AYGUN, 2013; AYGUN and BOZTOSUN, 2014; ZHUKOV et al. 1993).

^{6}He is still one of the hot topics of nuclear physics. Recently, MORCELLE et al. (2014) measured the elastic scattering angular distributions of the ^{6}He + ^{58}Ni reaction at E_{lab}=12.2, 16.5 and 21.7 MeV. They investigated the experimental data by using three-body Continuum Discretized Coupled Channels (CDCC) and four-body CDCC calculations. They reported that four-body CDCC calculations show a very well agreement with the experimental data. In the present paper, our aim is to theoretically investigate new measured elastic scattering angular distributions of the ^{6}He + ^{58}Ni reaction with different nuclear potentials. For this, we use both the phenomenological and the microscopic models based on the optical model (OM). All the theoretical results are compared with the results of the previous study (MORCELLE et al. 2014) as well as the experimental data.

In the next Section, the presentation of theoretical formalism is made. The theoretical results are given in Section III. Section IV is devoted to our summary and conclusions.

2.Theoretical Outline

Within the framework of the OM, the total potential can be written as the sum of nuclear and Coulomb potentials given by

$$V_{total}(r) = V_{Nuclear}(r) + V_{Coulomb}(r) \tag{1}$$

where the Coulomb potential (SATCHLER, 1983) due to a charge $Z_P e$ interacting with a charge $Z_T e$ distributed uniformly over a sphere of radius R_c is

$$V_{Coulomb}(r) = \frac{1}{4\pi\varepsilon_0}\frac{Z_P Z_T e^2}{r}, \qquad r \geq R_c \tag{2}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{Z_P Z_T e^2}{2R_c}\left(3 - \frac{r^2}{R_c^2}\right), \qquad r \leq R_c \tag{3}$$

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where R_c is the Coulomb radius, taken as $1.25(A_P^{1/3} + A_T^{1/3})$ fm in the calculations and Z_P and Z_T denote the charges of the projectile P and the target nuclei T, respectively.

A. Phenomenological approach

For phenomenological analysis based on the OM, the real and imaginary potentials are taken as the Woods-Saxon (WS) type in the following form

$$V_N(r) = -\frac{V_0}{1+\exp\left(\frac{r-R_V}{a_V}\right)} - i\frac{W_0}{1+\exp\left(\frac{r-R_W}{a_W}\right)}, \qquad (4)$$

where $R_i = r_i\,(A_P^{1/3} + A_T^{1/3})$ ($i = V$ or W), where A_P and A_T are the masses of projectile and target nuclei and r_V and r_W are the radius parameters of the real and imaginary parts of the nuclear potential, respectively. The two equations which give the depth-variations of the real and imaginary parts have been reported by KUCUK et al. (2009). In our work, first nuclear potential is obtained by using these equations and is attributed as WS.

B. Double folding model

The double folding model (DFM) is applied to obtain the real part of the optical potential. The DFM is acquired with the nuclear matter distributions of both projectile and target nuclei together with an effective nucleon-nucleon interaction potential (v_{NN}). In this way, the double folding (DF) potential is given by

$$V_{DF}(\boldsymbol{r}) = \int d\boldsymbol{r_1} \int d\boldsymbol{r_2}\, \rho_P(\boldsymbol{r_1})\, \rho_T(\boldsymbol{r_2}) v_{NN}(r_{12}) \qquad (5)$$

where $\rho_P(\boldsymbol{r}_1)$ and $\rho_T(\boldsymbol{r}_2)$ are the nuclear matter densities of projectile and target nuclei, respectively. For the projectile, we have used the Variational Monte Carlo (VMC) density distribution which is obtained from the VMC calculations using the Argonne v18 (AV18) two-nucleon and Urbana X three-nucleon potentials (AV18+UX). The VMC density of ^{6}He given in Fig. 1 is taken from Ref. (VMC). However, the density of the ^{58}Ni has been assumed as two-parameter Fermi (2pF) density distribution in the following form (FARID and HASSANAIN, 2000)

$$\rho(r) = \frac{\rho_0}{1+\exp(\frac{r-c}{z})} \quad , \qquad (6)$$

where ρ_0, c and z parameters are 0.172, 4.094 and 0.54, respectively.

The effective nucleon-nucleon interaction, v_{NN}, is integrated over both density distributions. We have used the M3Y nucleon-nucleon (Michigan 3 Yukawa) realistic interaction given by

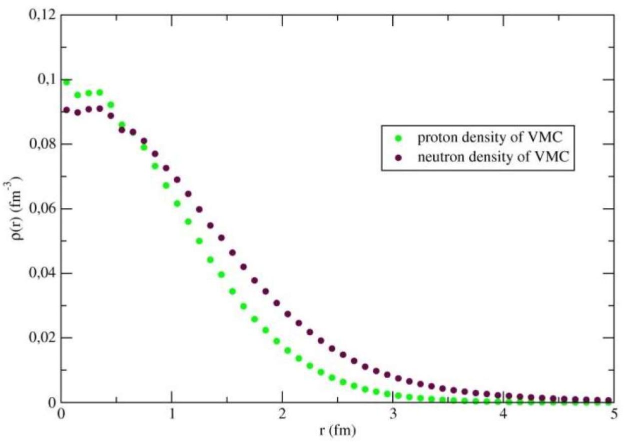

Figure 1. Proton and neutron density distributions in linear scale for ^{6}He nucleus.

$$v_{NN}(r) = 7999\frac{\exp(-4r)}{4r} - 2134\frac{\exp(-2.5r)}{2.5r} - J_{00}(E)\delta(r) \text{ MeV} \qquad (7)$$

where $J_{00}(E)$ represents the exchange term and can be expressed as

$$J_{00}(E) = 276\left[1 - 0.005\frac{E_{\text{lab}}}{A_P}\right] \text{MeV fm}^3. \qquad (8)$$

This potential is evaluated as DF(R) in the present work.

For the last nuclear potential, the real and imaginary parts are assumed as the folding potentials which have the same shape and different strengths. With this goal, the imaginary potential is applied as the folded potential multiplied by a normalization factor N_I. Thus, the ^{6}He + ^{58}Ni reaction can be expressed as

$$U_{total}(r) = U_{Coulomb}(r) - (N_R + N_I)V_{DF}(r). \qquad (9)$$

This potential (Eq. 9) is denoted as DF(R+I) in our study. The codes FRESCO (THOMPSON, 1988) and DFPOT (COOK, 1982) have been applied for all the calculations.

3. Results and Discussions

The angular distributions of the elastic scattering of the ^{6}He + ^{58}Ni reaction have been investigated for three different nuclear potentials at E_{lab}=12.2, 16.5 and 21.7 MeV. For this, firstly, we have obtained the phenomenological potential (WS) by using the equations reported by Ref. (KUCUK et al. 2009). Secondly, we have conducted the folding model calculations for the real potential based on the OM. In this respect, the imaginary potential has been taken as the volume WS potential. Finally, both the real and imaginary parts of the optical potential have been assumed as the folding potentials.

Thus, both potential are in the same shape and different strengths. While the theoretical calculations of the phenomenological model and the folding model have been performed, the values of the V_0, W_0, r_v, r_w, a_v and a_w potential parameters have been researched to obtain a good agreement fit with the experimental data. All the parameters have been listed in Tables I, II and III.

Table 1. Optical potential parameters used for the WS potential analysis of the ^{6}He + ^{58}Ni reaction at various energies.

Potential Type	E_{lab} (MeV)	V (MeV)	r_v (fm)	a_v (fm)	W (MeV)	r_w (fm)	a_w (fm)	σ (mb)
WS	12.2	133.224	0.90	0.70	7.643	1.50	0.70	1106.6
	16.5	136.019	0.90	0.70	6.998	1.50	0.70	1632.8
	21.7	139.399	0.90	0.70	6.218	1.50	0.70	1940.8

Table 2. Optical potential parameters obtained from the DF(R) potential analysis of ^{6}He + ^{58}Ni reaction.

Potential Type	E_{lab} (MeV)	N_R	W (MeV)	r_w (fm)	a_w (fm)	σ (mb)
DF(R)	12.2	0.63	10.0	1.39	0.5	822.7
	16.5	0.57	14.5	1.39	0.5	1334.4
	21.7	0.61	15.0	1.39	0.5	1676.8

Table 3. The normalization factors (N_R and N_I) for real and imaginary parts used in the DF(R+I) potential analysis of ^{6}He + ^{58}Ni reaction.

Potential Type	E_{lab} (MeV)	N_R	N_I	σ (mb)
DF(R + I)	12.2	0.55	0.35	908.4
	16.5	0.12	1.25	1646.6
	21.7	0.35	1.50	2100.4

The theoretical results achieved by using the WS, DF(R) and DF(R+I) potentials have been plotted in Figs. 2, 3 and 4 as compared with each other as well as the experimental data. We have observed that the DF(R+I) results are better than the results of DF(R) and WS potentials in general. However, we have noticed that the changes in the N_R and N_I values are large. Then, we have compared our results with the literature results (MORCELLE et al. 2014). As seen from Figs. 2, 3 and 4, the behavior of the our results are similar to 4b-CDCC results and our results are better than 3b-CDCC (Eb=1.6 MeV) results. Finally, we have given the cross-sections of all the nuclear potentials analyzed with this study. We have observed that the DF(R+I) cross-sections are bigger than the cross-sections of the other potentials in general.

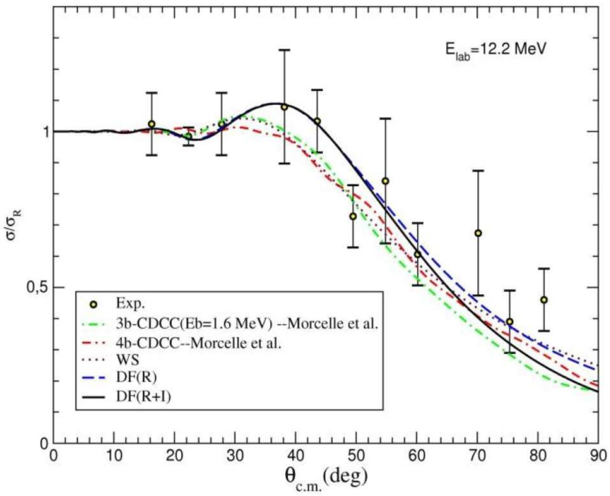

Figure 2. The elastic scattering angular distributions of the ^{6}He + ^{58}Ni reaction obtained from the optical model calculations employing WS, DF(R) and DF(R+I) potentials in comparison with the literature at 12.2 MeV.

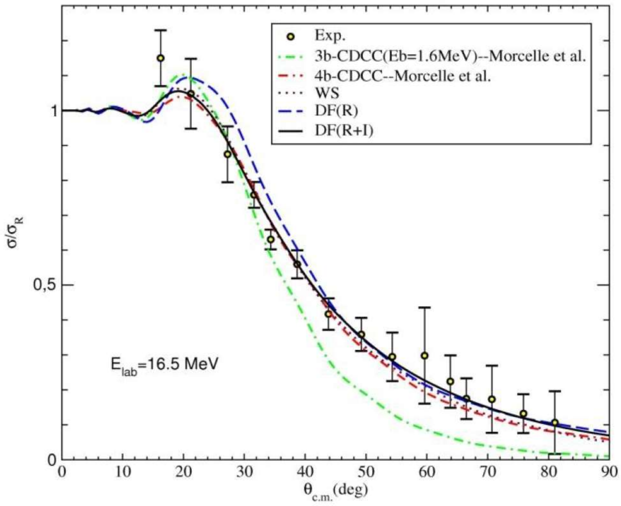

Figure 3. Same as in Fig. 2, but for 16.5 MeV.

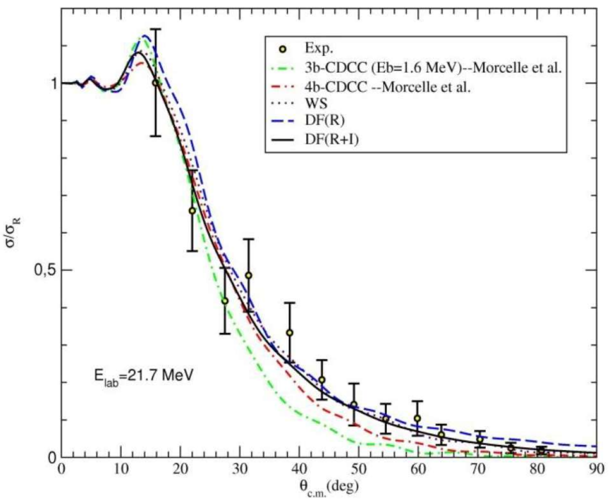

Figure 4. Same as in Fig. 2, but for 21.7 MeV.

In the present work, we have also gotten a simple equation for the imaginary potential varying with incident energy of the ^{6}He exotic nucleus. This equation is written as

$$W = 4.57 + 0.51\ \mathrm{E_{lab}} \tag{10}$$

where $\mathrm{E_{lab}}$ is the incident energy of the ^{6}He nucleus.

4. Summary and Conclusions

We have reanalyzed the elastic scattering angular distributions of ^{6}He scattered from ^{58}Ni at 12.2, 16.5, and 21.7 MeV. In this context, we have applied three different nuclear potentials. We have listed all the optical parameters in Tables. We have compared our results both with each other and the results of the literature as well as the experimental data. It has been seen that our results are better than 3b-CDCC (Eb=1.6 MeV) results. Also, we have observed that the DF(R+I) results are than better the results of the DF(R) and WS potentials. Consequently, this study has provided a comprehensive analysis on the validity of three different nuclear potentials of the ^{6}He + ^{58}Ni reaction.

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REFERENCES

AYGUN, M., KUCUK, Y., BOZTOSUN I. and IBRAHEEM, A. A. (2010), *Microscopic few-body and gaussian-shaped density distributions for the analysis of the ^{6}He exotic nucleus with different target nuclei*. Nuclear Physics, 848, 245-259.

AYGUN, M., BOZTOSUN, I. and SAHİN, Y. (2012), *A study on the Fresnel diffraction of ^{6}He by means of different microscopic density distributions*. Physics of Atomic Nuclei, 75, 963-968.

AYGUN, M., BOZTOSUN, I. and RUSEK, K. (2013), *Parametrized form of the dynamic polarization potential for the ^{6}He + ^{208}Pb interaction*. Modern Physics Letters A, 28, 1350112.

AYGUN, M. (2013), *A theoretical study on ^{120}Sn(^{6}He, ^{6}He)^{120}Sn elastic scattering*. Annals of Nuclear Energy, 51, 1-4.

AYGUN, M. and BOZTOSUN, I. (2014), *An extended analysis of the elastic scattering of ^{6}Li(^{6}He,^{6}He)^{6}Li system at 17.9 MeV*. Few-Body Systems, 55, 203-209.

COOK, J. (1982), *DFPOT - A program for the calculation of double folded potentials*. Computer Physics Communications, 25, 125-139.

FARID, M. EL-AZAB and HASSANAIN, M. A. (2000), *Density-independent folding analysis of the ^{6,7}Li elastic scattering at intermediate energies*. Nuclear Physics A, 678, 39-75.

KUCUK, Y., BOZTOSUN, I. and TOPEL, T. (2009), *Global optical potential for the elastic scattering of ^{6}He at low energies*. Physical Review C, 80, 054602.

MORCELLE, V., PİRES, K. C. C., RODRIGUEZ-GALLARDO, M., LICHTENTHÄLER, R., LÉPİNE-SZILY, A., GUIMARÃES, V., DE FARIA P. N., MENDES JUNIOR, D. R., MORO, A. M., GASQUES, L. R., LEISTENSCHNEIDER, E., PAMPA CONDORI, R., SCARDUELLI, V., MORAIS, M. C., BARIONI, A., ZAMORA, J. C., and SHORTO, J. M. B. (2014), *Four-body effects in the ^{6}He + ^{58}Ni scattering*. Physics Letters B, 732, 228-232.

SATCHLER, G. R. (1983), *Direct Nuclear Reactions* (Oxford University Press, Oxford).

THOMPSON, I. J. (1988), *Coupled reaction channels calculations in nuclear physics*. Computer Physics Reports, 7, 167-212.

VMC, Variational Monte Carlo density distribution, http://www.phy.anl.gov/theory/research/density/

ZHUKOV, M. V., DANILIN, B. V., FEDOROV, D. V., BANG, J. M., THOMPSON, I. J. and VAAGEN, J. S. (1993), *Bound state properties of Borromean halo nuclei: ^{6}He and ^{11}Li Review*. Physics Reports, 231, 151-199.