

Analysis of α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ for different nucleon-nucleon interactions

M. Aygun

Department of Physics, Bitlis Eren University, Turkey

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Abstract: The α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ is analyzed for six different nucleon-nucleon interactions which consist of FSUGold, NL1, NL2, NL3, TM1 and HS. The theoretical results are compared with the experimental data as well as the literature results. The similarities and differences of the investigated NN interactions are discussed.

Keywords: Relativistic mean field; nucleon-nucleon interaction; optical model; double folding model.

1 Introduction

The reaction behaviors of two colliding nuclei can be described through the nucleus-nucleus interaction potential. The optical model (OM) is one of the most effective models available for this purpose. The OM potential consists of the real and the imaginary parts. The real potential can be obtained by means of the double folding model (DFM) while the imaginary part is taken as the Woods-Saxon (WS) potential in general. The DFM needs to know two important inputs such as the nucleon-nucleon (NN) interaction and density distributions of projectile and target nuclei. Therefore, the NN interaction should be determined appropriately for the examined system.

In recent times, Aygun [1] investigated the α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ for ten different densities of ^{20}Ne projectile at 52.3 and 70 MeV. He proposed the alternative densities in order to calculate the reaction cross-section. We have noticed that the $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ reaction has been not analyzed for different types of NN interactions. As a result of this, we consider that the analysis of the effect of various NN interactions on the cross-section of the $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ reaction will be useful.

In this research, we examine the sensitivity to different NN interactions of α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$. In this respect, we apply six types of the NN interactions for the entrance channel which is considered as a dominant cause of theoretical uncertainty

in the analysis of the $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ reaction. We compare the agreement between the theoretical results and experimental data, and propose appropriate NN interaction(s) for the α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$.

2 Microscopic NN interactions

Different NN interaction potentials such as FSU Gold [2, 3], NL1 [4, 5], NL2 [5, 6], NL3 [6], TM1 [3, 7] and HS [8, 9] according to the parameters applied are reported by using the relativistic mean field (RMF) theory [10, 11]. The RMF theory is a microscopic approach evaluated to obtain a solution to many body problem in nuclear physics. It assumes that nucleons interact through meson exchange [12]. In this context, the effective RMF NN interaction can be given by

$$v_{NN}(r) = \frac{g_w^2}{4\pi} \frac{\exp(-m_w rc/\hbar)}{r} + \frac{g_\rho^2}{4\pi} \frac{\exp(-m_\rho rc/\hbar)}{r} - \frac{g_\sigma^2}{4\pi} \frac{\exp(-m_\sigma rc/\hbar)}{r} + \frac{g_\sigma^2}{4\pi} \text{rexp}(-2m_\sigma rc/\hbar) + \frac{g_\omega^2}{4\pi} \frac{\exp(-3m_\omega rc/\hbar)}{r} - \frac{\xi^2}{4\pi} \frac{\exp(-3m_w rc/\hbar)}{r} - J_{00}(E)\delta(r) \quad (1)$$

where g_w, g_ρ and g_σ are the coupling constants, and m_w, m_ρ and m_σ are the masses for w, ρ and σ mesons, respectively. The exchange term is written as

$$J_{00}(E) = -276 [1 - 0.005 \frac{E_{\text{Lab}}}{A_p}] \text{MeV fm}^3, \quad (2)$$

* Corresponding author e-mail: murata.25@gmail.com

where E_{Lab} and A_p are the incident energy and mass number of the projectile, respectively. To obtain the $V_{NN}(r)$ in terms of masses and coupling constants of the mesons, the parameter sets given in Table 1 are used. In order to make a comparative study, we perform the theoretical calculations for the M3Y effective NN interaction. Thus, we can discuss the similarities and differences of the investigated NN interactions. The M3Y used in the analysis of numerous nuclear reactions [13, 14, 15] is one of the most popular interaction potentials, which can be written as [16]

$$v_{NN}^{M3Y}(r) = 7999 \frac{e^{-4r}}{4r} - 2134 \frac{e^{-2.5r}}{2.5r} + J_{00}(E)\delta(r). \quad (3)$$

3 Transfer cross-section from the optical model

The transfer cross-section can be calculated in terms of the optical model given by

$$V_{\text{optical}}(r) = V_{\text{Real}}(r) + V_{\text{Imaginary}}(r). \quad (4)$$

The $V_{\text{Real}}(r)$ potential is produced over the double folding potential parameterized as

$$V(\vec{r}) = N_R \int d\vec{r}_1 \int d\vec{r}_2 \rho_P(\vec{r}_1) \rho_T(\vec{r}_2) v_{NN}[\vec{r} - (\vec{r}_1 - \vec{r}_2)], \quad (5)$$

where N_R is the renormalization factor, $\rho_{P(T)}(\vec{r}_{1(2)})$ is the density of projectile(target) and v_{NN} is nucleon-nucleon interaction. The imaginary part is assumed as the WS potential in the following form

$$W(r) = -iW_0(1 + e^x)^{-1}, \quad e^x = \frac{r - r_w (A_p^{1/3} + A_T^{1/3})}{a_w}, \quad (6)$$

where W_0 , r_w and a_w are the depth, radius, and diffuseness parameters. The codes DFPOT [17] and FRESKO [18] are used for the DFM and the OM calculations, respectively.

The different interactions for the analysis of $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ are assumed; entrance channel ($^{20}\text{Ne} + ^{28}\text{Si}$), exit channel ($^{32}\text{S} + ^{16}\text{O}$), core-core ($^{28}\text{Si} + ^{16}\text{O}$), binding potentials ($^{16}\text{O} + \alpha$ and $^{28}\text{Si} + \alpha$).

The nuclear potential of the entrance channel is

$$V_N(r) = N_R V_{NN-DF}(r) + i \frac{W_0}{1 + \exp\left(\frac{r - R_w}{a_w}\right)} \quad (7)$$

The nuclear potential of the exit channel is formulated by

$$V_N(r) = \frac{V_0}{1 + \exp\left(\frac{r - R_v}{a_v}\right)} + i \frac{W_0}{1 + \exp\left(\frac{r - R_w}{a_w}\right)} \quad (8)$$

The core-core and binding potentials are assumed as the sum of the real and the imaginary potentials in the WS type, similar to Eq. (8). Additionally, more detailed information about the theoretical calculations of the $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ alpha transfer reaction can be found in Ref. [1].

4 Results and Discussion

We have first calculated six various NN interactions for the theoretical analysis of α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ by using the code FORTRAN generated by us. We have displayed the changes depending the distance of all the NN interactions together with the M3Y NN interaction without the $J_{00}(E)$ term in Fig. 1. We have observed that the behavior of the NN interactions except for TM1 is similar to each other. The FSUGold, NL1, NL2, NL3 and HS NN interactions become repulsive, whereas the TM1 shows a attractive behavior. The FSUGold presents at large distance compared to other NN interactions while the M3Y arises at smaller distance.

The entrance channel is an important input in the theoretical analysis of the α -transfer reactions. Therefore, we apply different NN interactions for the entrance channel. We obtain the real potentials for the calculated NN interactions using the DFM. In this context, the default value of normalization constant (N_R), which is apply to increase the agreement between experiment and theory in the double folding calculations, is 1.0. We have accepted as $N_R=1.0$ for all the calculations. Additionally, the imaginary part is based on the WS potential, and the W_0 , r_w and a_w values of the potential have been adjusted to get well matched results with the experimental data. The determined values of W_0 , r_w and a_w are listed in Table 2.

Then, we have calculated the cross-section of $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ reaction at 52.3 MeV. We have demonstrated the theoretical results together with the experimental data in Fig. 2. We have observed that the results with the FSUGold, NL1, NL2 and NL3 NN interactions are very similar to each other, and are far from describing the experimental data. However, we have noticed that the result with the TM1 interaction is better than the results with the other NN interactions. We can say that the closest result to the M3Y has been found for the TM1 interaction. Also, we have observed that the M3Y result are better than the results with all the NN interactions.

Finally, we have obtained the α -transfer cross-section of $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ reaction at 70 MeV. We have compared the theoretical results and the experimental data in Fig. 3. We have observed that the results with the FSUGold, NL1, NL2, NL3 and HS NN interactions are very similar to each other. However, we have realized that the M3Y result is better than the results with the other NN interactions.

Table 1: The coefficients for the FSUGold, NL1, NL2, NL3, TM1 and HS NN interactions.

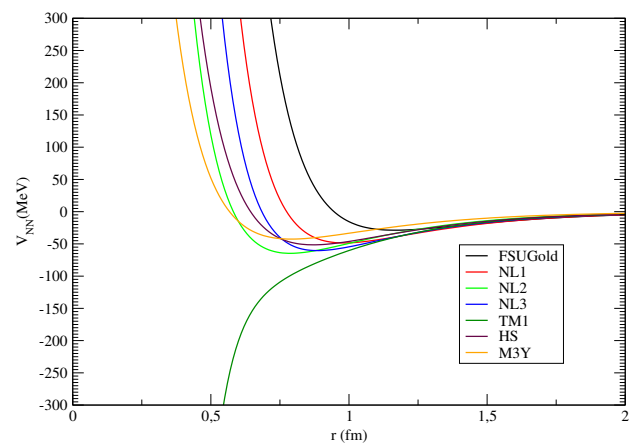
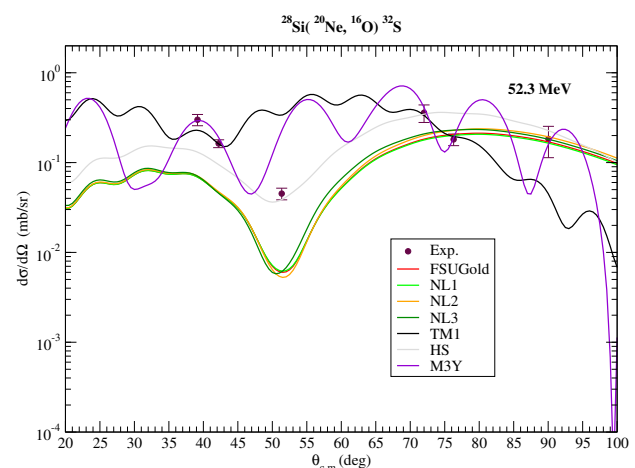
	FSUGold [2,3]	NL1 [4,5]	NL2 [5,6]	NL3 [6]	TM1 [3,7]	HS [8,9]
$m_w c^2/\text{MeV}$	782.5	795.359	780.0	782.501	783.0	783.0
$m_p c^2/\text{MeV}$	763.0	763.0	763.0	763.0	770.0	770.0
$m_\sigma c^2/\text{MeV}$	491.5	492.25	504.89	508.194	511.198	520.0
$g_w/(\text{MeV fm})^{1/2}$	14.298	13.285	11.493	12.868	12.614	13.8
$g_\rho/(\text{MeV fm})^{1/2}$	11.767	4.975	5.507	4.474	4.6320	8.08
$g_\sigma/(\text{MeV fm})^{1/2}$	10.592	10.138	9.111	10.271	10.0290	10.47
$g_2/(\text{MeV fm})^{1/2}$	-4.2380	-12.172	-2.304	-10.431	-7.2330	0
$g_3/(\text{MeV fm})^{1/2}$	-49.8050	-36.265	13.783	-28.885	0.6180	0
$\xi/(\text{MeV fm})^{1/2}$	20.046	0	0	-0.6	71.3070	0
$J_{00}/(\text{MeV fm}^{-3})$	276	592	592	592	276	276

Table 2: The potential parameters used in the calculations of the entrance channel for FSUGold, NL1, NL2, NL3, TM1 and HS interactions in the theoretical analysis of the α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$.

Channel	NN type	Energy (MeV)	W_0 (MeV)	r_w (fm)	a_w (fm)
$^{20}\text{Ne} + ^{28}\text{Si}$	FSUGold		4.00	1.40	0.90
	NL1		4.10	1.40	0.90
	NL2	52.3	3.60	1.40	0.90
	NL3		4.70	1.40	0.70
	TM1		3.10	1.25	0.50
	HS		3.20	1.40	0.70
$^{20}\text{Ne} + ^{28}\text{Si}$	FSUGold		5.10	1.40	0.70
	NL1		5.20	1.40	0.70
	NL2	70	5.20	1.40	0.70
	NL3		5.20	1.40	0.70
	TM1		8.20	1.30	0.60
	HS		5.10	1.40	0.70

5 Conclusions

In this research, we studied the α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ for six various NN interactions at 52.3 and 70 MeV. We calculated the cross-sections by using FSUGold, NL1, NL2, NL3, TM1 and HS interactions for the entrance potential. We observed that the TM1 interaction was the closest result to the M3Y at 52.3 MeV. We noticed that the results with the FSUGold, NL1, NL2, NL3 and HS interactions except for TM1 showed an average behavior with the experimental data at 70 MeV. Also, we compared our results with the M3Y results. We realized the results with M3Y NN interaction are better than the results with all the NN interactions.

**Fig. 1:** A comparison of FSUGold, NL1, NL2, NL3, TM1, HS and M3Y effective NN interactions as a function of distance.**Fig. 2:** The cross-sections of the α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ by using FSUGold, NL1, NL2, NL3, TM1 and HS NN interactions in comparison with the M3Y at 52.3 MeV. The data are from Ref. [19].

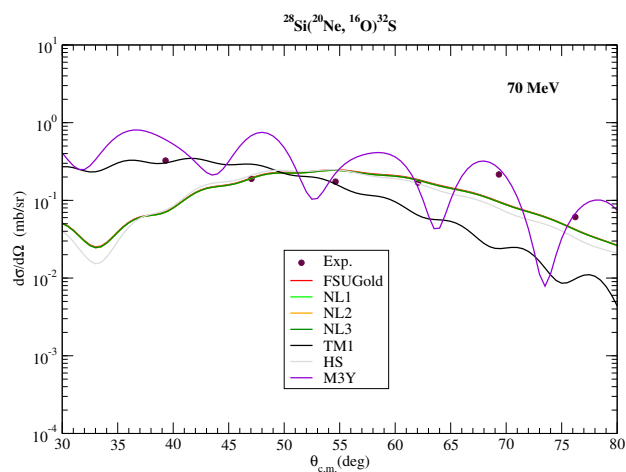


Fig. 3: The cross-sections of the α -transfer reaction $^{28}\text{Si}(^{20}\text{Ne}, ^{16}\text{O})^{32}\text{S}$ by using FSUGold, NL1, NL2, NL3, TM1 and HS NN interactions in comparison with the M3Y at 70 MeV. The data are from Ref. [19].

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