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A Theoretical Analysis of Quasi-elastic Scattering of ^{7}Li by ^{120}Sn Using Various Nuclear Potentials

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ABSTRACT

The quasi-elastic scattering data of ^{7}Li + ^{120}Sn reaction at E_{Lab} = 19.5, 20.5, and 25.0 MeV incident energies have been reanalyzed within the framework of the optical model. In order to obtain the real potential, seven different nuclear potentials have been used. The imaginary potential has been assumed in Woods-Saxon form. The theoretical results have been compared with each other as well as the experimental data.

Keywords: Nuclear potential, Optical model, Elastic scattering, Quasi-elastic scattering, ^{120}Sn

1. Introduction

The nuclear potential is an important tool in explaining the nuclear interactions such as elastic scattering, inelastic scattering, transfer reactions, breakup and knockout. With this goal, various nuclear potentials can be found in literature. Woods-Saxon [1], Woods-Saxon squared [2], Woods-Saxon derivative [3], Gaussian [4], Exponential [5] and Folding [6] potentials are some of them. This subject is still a problem of interest in the field of nuclear physics although different nuclear potentials can be obtained from the literature. Therefore, the introduction of alternative potentials is important in explaining various nuclear interactions.

Recenty, the quasi-elastic scattering data of ^{7}Li + ^{120}Sn reaction at E_{Lab} = 19.5, 20.5, and 25.0 MeV have been reported by Sousa et al. [7]. The experimental data have been analyzed by using the São Paulo Potential (SPP) within the framework of the optical model (OM). For this system, Aygun et al. [8] have conducted a theoretical study via phenomenological and double folding potentials and have obtained good agreement results with the experimental data. Zagatto et al. [9] have performed coupled channels (CC) and coupled reaction channels (CRC) calculations in order to explain the measured data of ^{7}Li + ^{120}Sn reaction. They have reported that some differences observed in the calculations may point out corrections to the nuclear potential or incorporation of further channels. As a result of this, it is thought that the analysis of different phenomenological potentials for ^{7}Li + ^{120}Sn reaction is important and useful in obtaining more knowledge about the nuclear interactions.

In the present research, the roles of various nuclear potentials are examined in explaining the experimental data of ^{7}Li + ^{120}Sn quasi-elastic scattering at 19.5, 20.5 and 25.0 MeV. In this way, seven different type nuclear potential are chosen for ^{7}Li + ^{120}Sn reaction. These are Gaussian-Gaussian (G-G), Exponential-Exponential (E-E), Yukawa-Yukawa (Y-Y), Woods Saxon-Woods Saxon (WS-WS), Woods Saxon Squared-Woods Saxon Squared (WS2-WS2), Gaussian-Yukawa (G-Y) and Gaussian-Woods Saxon (G-WS) potentials. All the theoretical results are compared with the experimental data. Finally, corresponding cross-section values for different nuclear potential calculations of ^{7}Li + ^{120}Sn reaction are given.

2. The Calculation Process

In theoretical manner, the total interaction potential between projectile and target nucleus can be written as

$$V_{total}(r) = V_C(r) + V_N(r) \quad (1)$$

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where V_C is Coulomb potential and V_N is nuclear potential. V_C (r) potential is given by [10]

$$V_C(r) = \frac{1}{4\pi\varepsilon_0}\frac{Z_P Z_T e^2}{r} \qquad r \geq R_C \tag{2}$$

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

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 projectile and target nucleus, respectively. For V_N potential, different nuclear potentials are applied. These seven different type potentials are described in the following section.

A. Gaussian-Gaussian (G-G) Potential

Firstly, Gaussian-Gaussian (G-G) potential is assumed to be for the real and imaginary parts of the optical potential. G-G nuclear potential is given by [11]

$$V_N^{G-G}(r) = -V_1 \exp\left[-\left(\frac{r-R_{v1}}{a_{v1}}\right)^2\right] - V_2 \exp\left[-\left(\frac{r-R_{v2}}{a_{v2}}\right)^2\right] \tag{4}$$

Where

$$R_i = r_i\,(A_P^{1/3} + A_T^{1/3}), \qquad i = v_1, v_2 \tag{5}$$

and A_P and A_T are mass numbers of projectile and target nucleus, respectively.

B. Exponential-Exponential (E-E) Potential

Secondly, in order to generate the real and imaginary parts of the optical potential, the used Exponential-Exponential (E-E) potential is parameterized by Ref. [11] as follows:

$$V_N^{E-E}(r) = -V_1 \exp\left[-\left(\frac{r-R_{v1}}{a_{v1}}\right)\right] - V_2 \exp\left[-\left(\frac{r-R_{v2}}{a_{v2}}\right)\right] \tag{6}$$

C. Yukawa-Yukawa (Y-Y) Potential

Thirdly, the real and imaginary potentials are considered as Yukawa-Yukawa (Y-Y) potentials parameterized by Ref. [11] as follows:

$$V_N^{Y-Y}(r) = -V_1 \frac{\exp\left[-\left(\frac{r-R_{v1}}{a_{v1}}\right)\right]}{r} - V_2 \frac{\exp\left[-\left(\frac{r-R_{v2}}{a_{v2}}\right)\right]}{r}. \tag{7}$$

D. Woods Saxon-Woods Saxon (WS-WS) Potential

Another nuclear potential investigated with this study is Woods Saxon-Woods-Saxon (WS-WS) potential given in the following form in Ref. [11]

$$V_N^{WS-WS}(r) = -\frac{V_1}{1+\exp\left(\frac{r-R_{v1}}{a_{v1}}\right)} - \frac{V_2}{1+\exp\left(\frac{r-R_{v2}}{a_{v2}}\right)}. \tag{8}$$

E. Woods Saxon Squared-Woods Saxon Squared (WS2-WS2) Potential

Woods Saxon Squared-Woods Saxon Squared (WS2-WS2) potential assumed for the optical potential is formulated by Ref. [11]

$$V_N^{WS^2-WS^2}(r) = -\frac{V_1}{\left[1+\exp\left(\frac{r-R_{v1}}{a_{v1}}\right)\right]^2} - \frac{V_2}{\left[1+\exp\left(\frac{r-R_{v2}}{a_{v2}}\right)\right]^2}. \tag{9}$$

F. Gaussian-Yukawa (G-Y) Potential

Here, in order obtain the real and imaginary parts of the nuclear potential, Gaussian-Yukawa (G-Y) potential is evaluated. This potential is parameterized by Ref. [11]

$$V_N^{G-Y}(r) = -V_1 \exp\left[-\left(\frac{r-R_{v1}}{a_{v1}}\right)^2\right] - V_2 \frac{\exp\left[-\left(\frac{r-R_{v2}}{a_{v2}}\right)\right]}{r} \tag{10}$$

G. Gaussian-Woods Saxon Potential (G-WS)

Finally, Gaussian-Woods Saxon (G-WS) potential is assumed as nuclear potential between the interacting two nuclei. It can be shown by Ref. [11]

$$V_N^{G-WS}(r) = -V_1 \exp\left[-\left(\frac{r-R_{v1}}{a_{v1}}\right)^2\right] - \frac{V_2}{1+\exp\left(\frac{r-R_{v2}}{a_{v2}}\right)} \tag{11}$$

3. Results and Discussion

The nuclear part of nucleus ^{7}Li + ^{120}Sn interaction potential has been calculated by using G-G, E-E, Y-Y, WS-WS, WS^2-WS^2, G-Y and G-W potentials. The angular distributions of ^{7}Li + ^{120}Sn scattering have been obtained within the framework of the Optical Model. The optical potential parameters and the cross-sections obtained from the theoretical calculations of the nuclear potentials have been listed in Table 1. In this study, χ^2/N values for all the potentials have also been calculated and given in Table 2.

Table 1. *The optical potential parameters and cross-sections obtained for G-G, E-E, Y-Y, WS-WS, WS^2-WS^2, G-Y and G-WS nuclear potentials of ^7Li + ^{120}Sn reaction investigated by using the OM.*

Energy (E_{Lab})	Potential type	V_1 (MeV)	r_{v1} (fm)	a_{v1} (fm)	V_2 (MeV)	r_{v2} (fm)	a_{v2} (fm)	σ_R (mb)
	G-G	20.0	0.850	0.660	10.80	1.632	0.200	141.5
	E-E	29.0	1.145	0.660	18.40	1.307	0.660	133.7
	Y-Y	70.0	1.150	0.660	11.80	1.603	0.680	144.7
19.5	WS-WS	60.0	1.180	0.515	19.50	1.412	0.512	132.6
	WS^2-WS^2	30.0	1.150	0.660	17.82	1.507	0.840	137.4
	G-Y	10.0	0.850	0.660	25.10	1.609	0.490	149.6
	G-WS	10.0	0.850	0.660	7.100	1.642	0.235	157.5
	G-G	68.0	1.457	0.700	15.00	1.240	0.700	166.9
	E-E	20.0	1.150	0.660	15.10	1.307	0.660	200.8
	Y-Y	37.6	1.384	0.660	18.00	1.490	0.660	169.4
	WS-WS	60.0	1.230	0.514	12.50	1.385	0.502	169.0
20.5	WS^2-WS^2	20.0	1.150	0.660	3.900	1.622	0.660	189.0
	G-Y	10.0	0.850	0.660	20.10	1.551	0.642	223.3
	G-WS	10.0	0.850	0.660	2.350	1.642	0.235	184.3
	G-G	23.0	1.470	0.830	16.80	1.346	0.530	921.2
	E-E	21.0	1.210	0.700	9.000	1.340	0.560	655.3
	Y-Y	30.0	1.410	0.660	25.00	1.430	0.660	673.1
	WS-WS	70.0	1.220	0.515	14.40	1.370	0.508	731.0
25.0	WS^2-WS^2	20.0	1.450	0.660	16.00	1.470	0.770	791.2
	G-Y	10.0	0.850	0.660	28.80	1.551	0.771	997.0
	G-WS	10.0	0.850	0.660	3.820	1.666	0.215	912.3

Table 2. *The χ^2/N values for G-G, E-E, Y-Y, WS-WS, WS^2-WS^2, G-Y and G-WS nuclear potentials in comparison with each other.*

	χ^2/N						
Energy (MeV)	Potential type						
	G-G	E-E	Y-Y	WS-WS	WS^2-WS^2	G-Y	G-WS
19.5	0.0771	0.0991	0.0871	0.0869	0.0829	0.0780	0.0843
20.5	0.174	0.0912	0.121	0.0991	0.105	0.146	0.114
25.0	2.14	1.71	2.38	1.55	1.82	2.24	2.48

In Fig. 1, the theoretical results have been presented in comparison with each other as well as the experimental data. It has been observed that the potentials have given different results according to their nuclear potential structure. While the differences between the results are clear at backwards angles, the results of some potentials are closer to each other at forwards angles. Especially, G-G, Y-Y and WS^2-WS^2 potentials gave close results in providing agreement with the experimental data. The smallest χ^2/N value was found for G-G potential. Also, the results have been compared with the theoretical results obtained by using the double folding model (DFM) by Aygun et al. [8]. It has been observed that G-G, Y-Y and WS^2-WS^2 results are in better agreement with the experimental data than the DFM results.

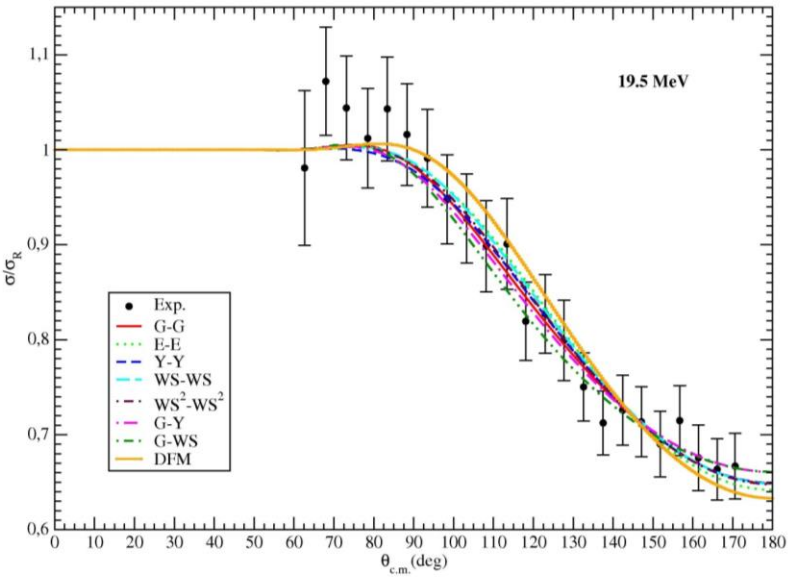

Fig. 1 *The elastic scattering angular distributions of ^{7}Li from ^{120}Sn at E_{Lab}=19.5 MeV by using G-G, E-E, Y-Y, WS-WS, WS^2-WS^2, G-Y and G-WS potentials in comparison with the experimental data. The experimental data have been taken from [7].*

The theoretical results of seven different nuclear potentials used in clarifying the quasi-elastic scattering data of ^{7}Li + ^{120}Sn reaction at E_{Lab}=20.5 MeV have been presented in Fig. 2. G-WS and WS^2-WS^2 results have displayed a very similar behavior and are in good agreement with the data in general. However, it has been seen that E-E potential has given better results than the other nuclear potentials. Also, this situation can be seen from χ^2/N values. In addition, the results have been compared with the DFM results [8]. It has been noticed that while the DFM results are similar to the other potential results at forward angles, they are different from each other at backward angles.

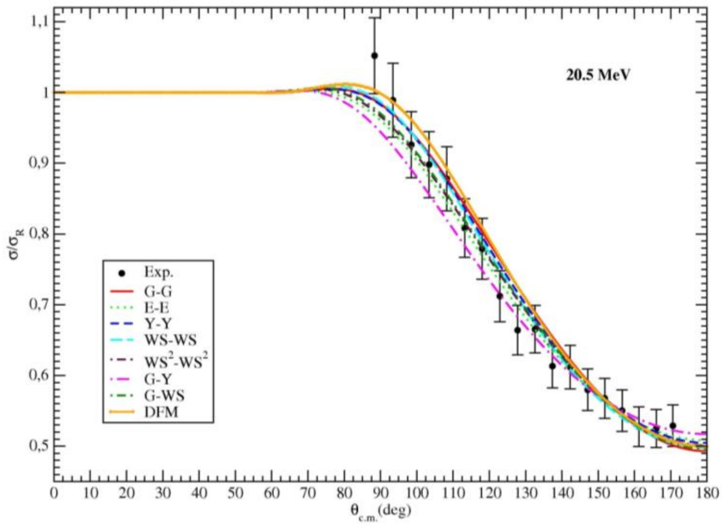

Fig. 2 *The elastic scattering angular distributions of ^{7}Li from ^{120}Sn at E_{Lab}=20.5 MeV by using G-G, E-E, Y-Y, WS-WS, WS^2-WS^2, G-Y and G-WS potentials in comparison with the experimental data. The experimental data have been taken from [7].*

The theoretical results of the angular distributions of ^{7}Li + ^{120}Sn system at E_{Lab}=25.0 MeV have been exhibited in Fig. 3. E-E and Y-Y results are the same with each other for $65^{\circ} \leq \Theta \leq 105^{\circ}$ but this harmony is broken at forwards angles. It has been noticed that the E-E and WS-WS nuclear potentials have produced better results in comparison with the other nuclear potentials. In general sense, while the potentials are in agreement with each other at forwards angles, the results differ from each other at backwards angles. Finally, the results for all the potentials investigated with this work have been presented in comparison with the DFM results [8]. It has been seen that E-E and WS-WS and DFM results are generally very close to each other at forwards angles and the DFM results are slightly better than the results of E-E and WS-WS potentials. However, at backwards angles, this harmony disappears and E-E results look a bit better than WS-WS and DFM results.

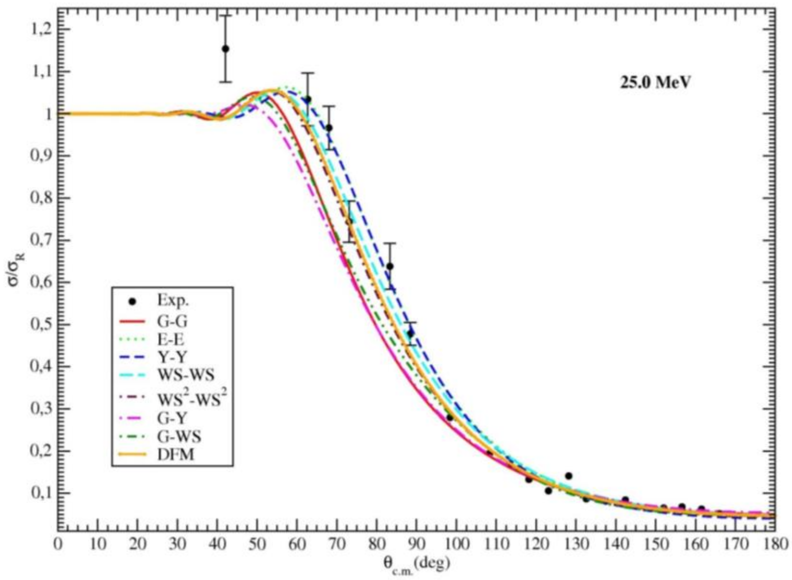

Fig. 3 *The elastic scattering angular distributions of ^{7}Li from ^{120}Sn at E_{Lab}=25.0 MeV by using G-G, E-E, Y-Y, WS-WS, WS^{2}-WS^{2}, G-Y and G-WS potentials in comparison with the experimental data. The experimental data have been taken from [7].*

4. Conclusion

In the present work, the angular distributions of the quasi-elastic scattering of ^{7}Li by ^{120}Sn have been investigated at incident energies of 19.5, 20.5, and 25.0 MeV. The cross-sections have been obtained by using seven different nuclear potentials based on the Optical Model. The obtained theoretical results are in agreement with the experimental data have been obtained. It has been seen that the nuclear potential parameters are not the same for all the potentials. It is thought that it indicates the shape-dependency of the optical potential. Finally, it can be said that to investigate the comparison of the well-known potentials in literature is important and useful for the analysis of nuclear reactions. It is believed that the present study can be used as a guide for examining the experimental data with different nuclear potentials.

Conflicts of Interest

The authors have no conflict of interest.

References

[1] R.D Woods. and D.S. Saxon, “Diffuse Surface Optical Model for Nucleon-Nuclei Scattering”, Phys. Rev. 95, 577-578 (1954).

[2] P Schwandt. S. Kai1as, W.W. Jacobs, M.D. Kaitchuck, W. Ploughe and P.P. Singh, “Optical potential for ^{6}Li + ^{28}Si elastic scattering at 154 MeV”, Phys. Rev. C. 21, 1656(R) (1980).

[3] M. Aygun, I. Boztosun and K. Rusek, “Parametrized form of the dynamic polarization potential for the ^{6}He + ^{208}Pb interaction”, Mod. Phys. Lett. A 28, 1350112 (2013).

[4] M. Aygun, Y. Kucuk, I. Boztosun and A. A. Ibraheem, “Microscopic few-body and Gaussian-shaped density distributions for the analysis of the ^{6}He exotic nucleus with different target nuclei”, Nucl. Phys. A 848, 245-259 (2010).

[5] M. Lozano and G. Madurga, “Exponential optical potentials for heavy-ion elastic scattering”, Nucl. Phys. A 334, 349-364 (1980).

[6] M. Aygun, “Double-folding analysis of the ^{6}Li + ^{58}Ni reaction using the ab initio density distribution”, Eur. Phys. J. A 48, 145 (2012).

[7] D.P. Sousa, D. Pereira, J. Lubian, L.C. Chamon, J.R.B. Oliveira, E.S. Rossi, C.P. Silva, P.N. de Faria, V. Guimarães, R. Lichtenthaler and M.A.G. Alvarez, “Probing the ^{6,7}Li nucleon densities through a new break-up process approach”, Nucl. Phys. A 836, 1-10 (2010).

[8] M. Aygun and Z. Aygun, “A study on ^{7}Li + ^{120}Sn quasi-elastic scattering”, Turk. J. Phys. 40, 12-23 (2016).

[9] V.A.B. Zagatto, J.R.B. Oliveira, L.R. Gasques, J.A. Alcántara-Núñez, J.G. Duarte, V.P. Aguiar, N.H. Medina, W.A. Seale, K.C.C. Pires, A. Freitas, J. Lubian, J.M.B. Shorto, F.A. Genezini and Jr E.S Rossi., “Elastic and inelastic angular distributions of the ^{7}Li+ ^{120}Sn system for energies near the Coulomb barrier”, J. Phys. G: Nucl. Part. Phys. 43, 055103 (2016).

[10] G.R. Satchler, Direct Nuclear Reactions, Oxford University Press, Oxford (1983).

[11] I. J. Thompson, Fresco version 2.9, http://www.fresco.org.uk, (Accessible on: September 2011).