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Optical Model Potential of $A = 3$ projectiles for $1p$-shell nuclei

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Abstract

A set of global optical potential parameters describing the $A = 3$ particles (^{3}He and ^{3}H) elastic scattering from $1p$-shell nuclei, HT1p, is obtained by simultaneously fitting 118 sets of experimental data of ^{3}He and ^{3}H elastic scattering from ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C, ^{14}C, ^{14}N, ^{15}N, ^{16}O, ^{17}O and ^{18}O with incident energies from $4 \leqslant E \leqslant 118.5$ MeV and 24 sets of elastic scattering data with the ^{6}Li and ^{7}Li targets from $3 \leqslant E \leqslant 44$ MeV. HT1p is found to be superior to GDP08 [D.Y. Pang, P. Roussel-Chomaz, H. Savajols, R.L. Varner, and R. Wolski, Phys. Rev. **C79**, 024615 (2009)], which is a systematic potential designed for the heavy-target region, in reproduction of the angular distributions of elastic scattering cross sections of ^{3}He and ^{3}H from $1p$-shell nuclei at energies below 100 MeV. At energies above 100 MeV, GDP08 is found to be better than HT1p.

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I. INTRODUCTION

Systematic optical model potentials (SOMPs) are necessary inputs for direct nuclear reactions models, which are widely used in studies of nuclear structures and nuclear astrophysics. The importance of SOMPs in such studies are not only shown in cases when experimental data of elastic scattering cross sections are not available, but also in other works, such as systematic study of spectroscopic factors using, for example, (d, p), (p, d), and $(^3\mathrm{He}, d)$ reactions. In such studies, systematically consistent results can only be obtained when SOMPs are used [1–3]. When exploring into unknown regions, either in nuclear chart that are far away from the β-stability line or in some key nuclear reactions in nuclear astrophysics which are very difficult or even not possible to measure directly with current facilities, reliable predictions of theoretical models, or at least the understanding of the uncertainties of the various theoretical models are crucial [4]. Uncertainties in optical model potentials consists one of the main sources of uncertainties in predictions of direct nuclear reactions (see, e.g. Ref.[5]). It is thus important to develop OMPs, which are obtained by optimizing descriptions of scattering observable, usually angular distributions of elastic scattering cross sections (ADXSECs), over a wide range of incident energies and nuclear masses. Systematic OMPs obtained in this way minimize the uncertainties of OMPs as inputs in direct nuclear reactions.

Over the many years, a lot of efforts have been made in developing SOMPs for nucleon ($A = 1$) [6–9], deuteron ($A = 2$) [10–13], ^{3}H and ^{3}He ($A = 3$) [14–18], alpha-particles ($A = 4$) [19–22], and heavy ions ($A \geq 6$) [23–25]. However, most of these potentials are based on analysis of ADXSECs of projectiles from heavy targets with atomic masses of, typically, $A_\mathrm{T} \geq 30$. It is well-known that the systematic behaviour, namely, the energy- and target-mass-dependence of depth and geometry parameters of OMPs are quite different between heavy and light nuclei regions [16, 22, 26]. Although these SOMPs are very often extrapolated to nuclei with $A_\mathrm{T} < 30$ [1, 27, 28], they are not optimized for those regions. It has been found that some modification of these potentials should be made in order to best reproduce experimental data with light particles [29]. Systematic OMPs for light nuclei should be developed whenever possible. Besides such practical purposes, a SOMP established in the light-target region, which are not as much studied as in the heavy-target region, will quantify the differences in the behaviour of SOMPs between light- and heavy-mass regions,

and will be helpful in finding a proper parameterization that aims to cover both mass regions. The relative difference in the target masses are much larger in the light-mass region than that in the heavy-mass region, for example, the difference in masses of ^{9}Be and ^{10}B is 10% while that between ^{40}Ca and ^{41}Ca is only 2.5%. The differences in energy-level densities among light nuclei are also larger than that of the heavy ones. It is thus questionable if a systematic potential can be obtained for a light-mass region. Nevertheless, some successful pioneer work have been made for the 1p-shell nuclei, namely, for nuclei with atomic numbers ranging from 3 to 8, for protons and neutrons [30] and heavy-ions [31].

In this paper, we report a SOMP of ^{3}He and ^{3}H on 1p-shell nuclei, designated as HT1p (H and T being initials of helion and triton, respectively). This potential is obtained by simultaneously fitting 118 sets of ADXSEC data of ^{3}He and ^{3}H elastic scattering from ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C, ^{14}C, ^{14}N, ^{15}N, ^{16}O, ^{17}O, and ^{18}O. The incident energies covered by these experimental data are from 3.7 MeV to 118.5 MeV. The potential for ^{6}Li and ^{7}Li are searched separately from the other 1p-shell nuclei with incident energies from 3 to 44 MeV. As we show in Section II B, the OMP parameters for these two nuclei differ significantly from the other 1p-shell nuclei. This may be attributed to their weak binding energies or ^{3}He or ^{3}H cluster structure.

This paper is organized as the following: the parameterization of the SOMP is introduced in Section II A; the resulting parameters are reported in Section II B with comparisons between optical model calculations and experimental data; discussions on the applicable energy ranges of HT1p and GDP08, and volume integrals of these potentials are given in Section III. Our conclusions are made in Section IV.

II. PARAMETERIZATION AND DETERMINATION OF THE SYSTEMATIC POTENTIAL PARAMETERS

A. Parameterization of HT1p

The parameterization of HT1p for the 1p-shell nuclei is the same as that of GDP08[16] except for the introduction of an energy-dependence parameter to the real potential radius. For this reason, we simply recapitulate the necessary equations and refer Ref.[16] for detailed discussions about this parameterization. The phenomenological optical model potential, as

a function of the radial distance between the center-of-masses of the projectile and the target nuclei, r, is defined as:

$$\begin{aligned} U(r) \;=\; & -V_{\rm r} f_{\rm ws}(r, R_0, a_0) - iW_{\rm v} f_{\rm ws}(r, R_{\rm w}, a_{\rm w}) \\ & -iW_{\rm s}(-4a_{\rm w})\frac{d}{dr} f_{\rm ws}(r, R_{\rm w}, a_{\rm w}) \\ & +V_{\rm C}(r), \end{aligned} \tag{1}$$

where $V_{\rm r}$, $W_{\rm v}$, and $W_{\rm s}$ are depths of the real, volume-imaginary, and surface-imaginary parts, respectively. $f_{\rm ws}$ is the Woods-Saxon form factor:

$$f_{\rm ws}(r, R, a) = \frac{1}{1 + \exp\left[(r - R)/a\right]}, \tag{2}$$

with R and a being the geometry parameters (radius and diffuseness) of the potential. $V_{\rm r}$, $W_{\rm v}$, $W_{\rm s}$, have their associate R and a values, distinguished by their subscripts as is shown in Eq.(1). $V_{\rm C}$ is the Coulomb potential:

$$V_{\rm C}(r) = \begin{cases} \dfrac{Z_{\rm P} Z_{\rm T} e^2}{r}, & (r \geqslant R_{\rm C}) \\ \dfrac{Z_{\rm P} Z_{\rm T} e^2}{2R_{\rm C}} \left(3 - \dfrac{r^2}{R_{\rm C}^2}\right), & (r \leqslant R_{\rm C}), \end{cases} \tag{3}$$

with $Z_{\rm P}$ and $Z_{\rm T}$ being the charge numbers of the projectile and targets nuclei, respectively and, $R_{\rm C}$ is the radius of the Coulomb potential, which is defined as $R_{\rm C} = r_{\rm c} A_{\rm T}^{1/3}$ ($A_{\rm T}$ is the mass of the target in the atomic mass unit). It was found that the angular distributions of elastic scattering cross sections are not much sensitive to the values of Coulomb radius. In this work, we fix $r_{\rm c} = 1.3$ fm for all target nuclei.

We parameterize the energy- and target-mass dependence of the depth and geometry parameters as the following:

1. The depth of the real part of nuclear potential is:

$$V_{\rm r} = V_0 + V_{\rm e}(E - E_{\rm C}), \tag{4}$$

where $E_{\rm C}$ is the Coulomb correction to the incident energy, which is taken to be the average value of the Coulomb potential inside the nucleus[7, 10, 16]:

$$E_{\rm C} = \frac{6 Z_{\rm P} Z_{\rm T} e^2}{5 R_{\rm C}}. \tag{5}$$

Note that Eq. (5) imply a $Z_{\rm T} A_{\rm T}^{-1/3}$ term in the real potential that has been introduced in the previous works (see, e.g., Refs. [17, 18, 32, 33]).

2. The depth of the volume and surface imaginary potentials, $W_{\rm v}$ and $W_{\rm s}$, respectively, are functions of the incident energy E:

$$W_{\rm v}(E) = \frac{W_{\rm v0}}{1+\exp\left(\frac{W_{\rm ve0}-(E-E_{\rm C})}{W_{\rm vew}}\right)}, \tag{6}$$

$$W_{\rm s}(E) = \frac{W_{\rm s0} \pm W_{\rm st}\varepsilon}{1+\exp\left(\frac{(E-E_{\rm C})-W_{\rm se0}}{W_{\rm sew}}\right)}, \tag{7}$$

where $\varepsilon = (N_{\rm T}-Z_{\rm T})/A_{\rm T}$ is the isospin asymmetry of the target nucleus, the "+" and "−" signs are for ^{3}He and ^{3}H projectiles, respectively.

3. The radius of the real potential consists of the term that is proportional to $A_{\rm T}^{1/3}$, the offset term, and the energy-dependence term:

$$R_0 = r_0 A_{\rm T}^{1/3} + r_0^{(0)} + r_{0\rm e}(E-E_{\rm C}). \tag{8}$$

The energy dependence of the geometry parameters, which might not to be necessary in systematic potentials of nucleons [7, 8], was found necessary for composite particles, such as, deuterons [12] and α-particles [21], when a large range of incident energies is covered. The diffuseness parameter a_0 is assumed to be independent on target masses and incident energies.

4. The volume and surface imaginary potentials are assumed to have the same geometry parameters:

$$R_{\rm wv} \equiv R_{\rm ws} = R_{\rm w} = r_{\rm w} A_{\rm T}^{1/3} + r_{\rm w}^{(0)}, \tag{9}$$

and, like that of the real potential, the diffuseness parameters $a_{\rm wv} \equiv a_{\rm ws} = a_{\rm w}$ are assumed to be independent on $A_{\rm T}$ and E. Addition of the energy dependent term, $r_{\rm we}(E-E_{\rm C})$, to $R_{\rm w}$ has been attempted. It is found that $r_{\rm we}$ is not well determined by the experimental data included in this work, namely, its values was determined with an uncertainty that is larger than itself and addition of this parameter did not provide an apparent improvement to the description of the experimental data. Because of this, we do not include the energy dependence to the geometry parameters of the imaginary potentials in the current work.

Only experimental data of ADXSECs are used in this work and most of which do not cover backward angles. These data do not confine the spin-orbit potentials sufficiently well

[26]. Because of this, we do not include the spin-orbit potentials in our parameterization in this work. All energies quoted in the text, or in the equations, are projectile incident energies in the laboratory system.

B. Determination of the systematic OMP parameters for $1p$-shell nuclei

Experimental angular distributions of elastic scattering cross sections are used to confine the SOMP parameters. The database consists of 118 sets of data for target nuclei of ^{9}Be, ^{10,11}B, $^{12-14}$C, ^{14,15}N, and $^{16-18}$O with the incident energies from 3.7 to 118.5 MeV and 24 sets for ^{6}Li and ^{7}Li from 3 to 44 MeV. Because ^{6}Li and ^{7}Li are very weakly-bound with ^{3}He/^{3}H cluster structure, we would expect that the potential systematics with these isotopes do not consistent with the systematics established for other $1p$-shell nuclei. Actually, this is confirmed by our results (see Table.II). Because of this, the potential parameters of ^{6}Li and ^{7}Li are searched separately. The coverage of target masses and incident energies of the data sets is depicted in Fig.1. More detailed information about the database is listed in Table I. All the data sets used in this work are digitized from their original papers except for ^{3}H elastic scattering on ^{6}Li at 3-10 MeV [34], which are taken from the nuclear database EXFOR[35].

The systematic OMP parameters are determined by the usual criteria of the minimum deviation of results of optical model calculations from the experimental data, which is defined as

$$Q^2 = \frac{1}{N}\sum_{i=1}^{N}\frac{\left[\sigma_i^{\rm exp} - \sigma_i^{\rm th}\right]^2}{\Delta\sigma_i^2}, \tag{10}$$

where N is the number of data points, $\sigma_i^{\rm exp}$ and $\sigma_i^{\rm th}$ are the experimental and theoretical differential cross sections, respectively, and $\Delta\sigma_i$ is the uncertainty of the experimental cross sections. Q^2 in literature is usually called χ^2. However, as in CH89 and GDP08, we retain the notation of Q^2 because, as was discussed in Ref. [7], this value, which is estimated by simultaneously fitting many sets of experimental data from different sources with different assertions of uncertainties, does not obey the χ^2 distribution. Since different data sets measured by different groups using different facilities have different uncertainties, using reported experimental uncertainties in the global fitting may put some unreasonable weight to some specific data sets. Because of this, we assume a uniform uncertainty of 15% for all the

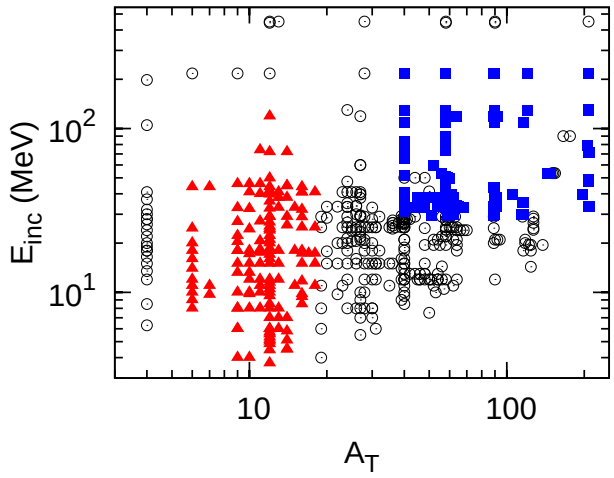

FIG. 1: (Color online) Incident energy and target mass distributions covered by the database of the angular distributions of the differential cross sections collected for ^{3}He elastic scattering from atomic nuclei. The squares represent those included in GDP08, the triangles are used for HT1p, and the circles are those unexplored by us.

data sets in the database. We allow variations of the normalization of the experimental data during the parameter fitting. Values of the parameters are determined using the computer code MINOPT [7], which is a combination of the optical model program OPTICS[36] and the multi-parameter minimization program, MINUIT[37]. It allows us to optimize the OMP parameters *simultaneously* by fitting a big set of experimental data which covers a large range of target masses and incident energies.

The details of fitting procedures are the same as those elaborated in Ref. [16] and we omit them in the present paper. The resulting SOMP parameters for the $A = 3$ particles with the $1p$-shell nuclei are listed in Table.II. The parameter values of GDP08 are also shown for comparisons. The uncertainties of these parameters are determined with the bootstrap uncertainty analysis method [87], which simulates many repeated measurements of the data by creating new data sets of the same size as those in the original database using random sampling with replacement (see Ref. [7] for details of the bootstrap method). The parameter uncertainties are obtained with 1000 resamplings. The energy-dependence parameters of the imaginary potential, $W_{\rm ve0}$, $W_{\rm vew}$, $W_{\rm vs0}$ and $W_{\rm sew}$ in Eq. 6, are found to be not well-determined by the experimental data included in this work. For example, when we allowed these four parameters to vary, we got $W_{\rm vew} = 2.08\pm3.18$ MeV and $W_{\rm sew} = 71.9\pm74.3$

TABLE I: References for the data sets used in searching of the optical model parameters.

heilum								
target	Elab	Ref	target	Elab	Ref	target	Elab	Ref
^{6}Li	8,9,10 11,12,14 16,18,20	[38]	^{12}C	8.5, 10	[39]	^{14}C	37.9	[40]
	24.6, 27	[41]		9.5, 10.5 11.5	[42]		44.8	[43]
	33.3	[44]		11	[45]		72	[46]
	44	[47]		12, 15	[48]	^{14}N	4.5, 7	[49]
^{7}Li	33.3	[44]		15	[50]		25.7, 29	[51]
	44	[47]		18, 20, 21	[52]		26.3	[53]
^{9}Be	4, 6, 8 10, 15, 18	[54]		18.6, 20 22.2, 23.9	[55]		44.6	[43]
	6, 8, 18	[56]		24.5, 25.3 26.8	[51]	^{15}N	11	[42]
	13.2, 20.4 22.2, 27	[57]		28.95	[58]		18	[59]
	32.8	[60]		29	[61]		33	[62]
	46.1	[47]		32.6	[60]	^{16}O	25	[63]
^{10}B	4, 8, 10 12, 15, 18	[64]		36, 42	[65]		28.9	[51]
	9.8	[66]		39.7	[67]		40.9	[68]
	11	[42]		40.9	[68]		41	[69]
	13.2, 17.2 24.3	[57]		41	[69]		44	[47]
	32	[70]		44	[47]	^{17}O	11	[42]
	41	[69]		49.8	[43]		17.3	[71]
	46.1	[47]		72	[72]		33	[73]
^{11}B	8, 15	[54]	^{13}C	6, 8	[74]	^{18}O	11	[42]
	10, 12, 18	[75]		12, 15, 18	[48]		11	[76]
	17.5, 40	[77]		33	[62]		15	[50]
	18.3, 20.6 27.2	[57]		37.9	[40]		17.3	[71]
	46.1	[47]		37.9	[78]		25	[63]
	74	[79]		41	[69]		33	[73]
^{12}C	3.7	[80]	^{14}C	10, 12 15, 18	[64]		41	[69]
	6	[74]		29	[51]			

triton								
target	Elab	Ref	target	Elab	Ref	target	Elab	Ref
^{6}Li	3, 4, 5 6, 7, 8 9,10	[34]	^{12}C	36	[81]	^{16}O	33	[82]
	17	[83]		38	[84]		36	[81]
^{12}C	20	[85]	^{13}C	38	[84]			
	33	[82]	^{14}C	72	[86]			

MeV, and Q^2, with the number of free parameters increased from 12 to 16, only changed from 63.0 to 61.8. For this reason, we keep the values of these parameters to be the same as those in GDP08. Similarly, the volume absorption part and the energy dependence of the real potential radius for ^{6,7}Li are ignored.

TABLE II: Values (P) and their uncertainties ΔP of the parameters in the systematic optical potentials for $A = 3$ nuclei. V_0, V_e, $W_{\rm V0}$, $W_{\rm S0}$, $W_{\rm ST}$, $W_{\rm ve0}$, $W_{\rm vew}$, $W_{\rm se0}$, and $W_{\rm sew}$ are in MeV and r_0, $r_0^{(0)}$, $r_{0\rm ae}$, a_0, $r_{\rm w}$, $r_{\rm w}^{(0)}$, and $a_{\rm w}$ are in fm.

	$1p$		^{6,7}Li		GDP08	
parameter	P	ΔP	P	ΔP	P	ΔP
V_0	155.1	1.6	80.1	7.7	118.3	1.3
V_e	-0.678	0.027	-0.61	0.21	-0.13	0.01
r_0	0.920	0.009	1.48	0.13	1.3	0.01
$r_0^{(0)}$	0.108	0.017	-	-	-0.48	0.05
$r_{0\rm ae}$	0.0031	0.0002	-	-	-	-
a_0	0.792	0.002	0.590	0.044	0.82	0.01
$W_{\rm V0}$	33.1	2.3	-	-	38.5	3.9
$W_{\rm S0}$	21.8	0.6	25	10	35.0	1.1
$W_{\rm ST}$	13.1	4.5	-	-	34.2	8.0
$r_{\rm w}$	1.43	0.04	0.83	0.24	1.312	0.02
$r_{\rm w}^{(0)}$	-0.16	0.10	-		-0.129	0.10
$a_{\rm w}$	0.801	0.010	1.047	0.098	0.84	0.01
$W_{\rm ve0}$	156.1	-	-	-	156.1	11.9
$W_{\rm vew}$	52.4	-	-	-	52.4	8.2
$W_{\rm se0}$	30.8	-	30.8	-	30.8	4.7
$W_{\rm sew}$	106.4	-	106.4	-	106.4	8.0

It is interesting to compare the values of parameters of HT1p with that of CH89, which were determined for the heavy-target and, generally, higher energy region (see Fig. 1 for comparison). We can conclude that:

1. The depth of the real potentials are larger for the light targets than for the heavy targets. This is consistent with Trost *et al.* [26]. It would be interesting to see if microscopic theories of optical model potentials can explain this systematic difference between light and heavy targets.

2. The depth of the imaginary potentials for the light targets are smaller than for the heavy targets. This is also consistent with Trost *et al.* [26]. The systematically weaker absorption in the light-target region may relate to the fact that the average energy level densities in this region is smaller than that in the heavy-target region.

3. The radius parameter, r_0, of the real potentials of light targets is much smaller than that of heavy targets, and the effective reduced radius parameter $r_0(1 + r_0^{(0)} A_{\rm T}^{-1/3})$ depends oppositely on target-masses in these two mass regions. On the other hand, the radius parameter of the imaginary potentials for light targets are larger than that of heavy targets.

The parameters of ^{6,7}Li show very different behaviour from the other $1p$-shell nuclei. This may relate to weak-bounding nature of these two nuclei and their cluster structures. Of course, one should also note that these parameters with the Lithium isotopes are determined with a much smaller database and most of the data are in the low-energy region, which do not constraint the potential parameters sufficiently well. As expected, the deficiency of the database for the Lithium isotopes results in big uncertainties of the parameters, which are clearly shown in Table II.

III. DISCUSSIONS

A. Energy region of applicability of HT1p

In Figs. 2, 3 and 4 we show the comparison of the optical model calculations with the ADXSECs and the experimental data. Results obtained using GDP08 are also shown. Although the details of these comparisons can not be shown clearly for each single case, these figures suggest that, with respect to GDP08, which was determined by fitting the data for target masses $A_{\rm T} \geq 40$, there is an overall improvement in reproduction of the experimental data with HT1p.

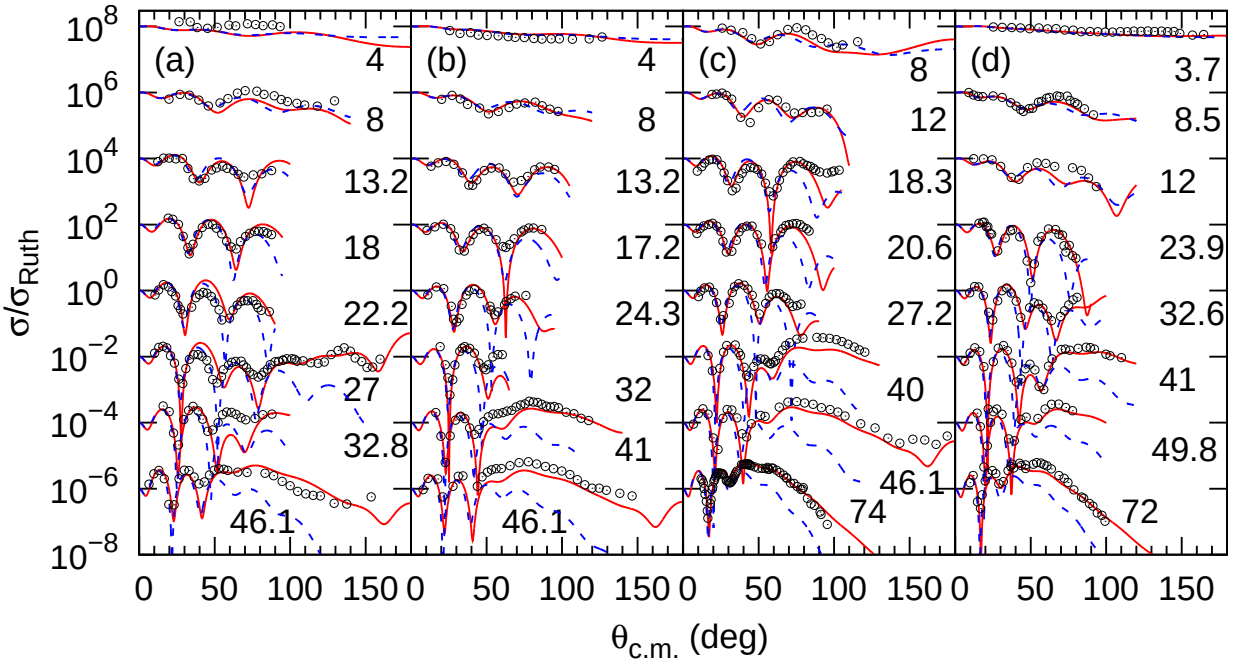

FIG. 2: (Color online) Optical model calculations of the angular distributions and their comparisons with the experimental data for ^{3}He elastic scattering from (a) ^{9}Be, (b) ^{10}B, (c) ^{11}B, and (d) ^{12}C. The cross sections are scaled by factors of 10^2. The incident energies are indicated in the figures in unit of MeV. The solid and dashed curves are results of the optical model calculations with the systematic potential with 1p-shell nuclei and that with GDP08 [16].)

Since all of the experimental data included in this work have incident energies not exceeding 74 MeV (the only exception is ^{3}He+^{12}C scattering at $E = 118.5$ MeV), the present systematic potential focuses only on the low energy region for the 1p-shell nuclei. As we see from Figs. 2, 3 and 4, within such an energy region, this potential reproduces the elastic scattering cross sections well. However, for incident energies larger than 74 MeV (unfortunately, to our knowledge, there are no experimental data between 74 and 118 MeV), GDP08 is better than HT1p in reproduction of the ADXSECs. Success of GDP08 in reproducing the ^{3}He elastic scattering from light nuclei, which are very far away from the region where it is determined, such as ^{6}Li, ^{9}Be, and ^{12}C, at energies larger than around 100 MeV, are shown in Fig. 11 of Ref. [16]. This is illustrated again in Fig. 5, where we show the failure of HT1p compared to GDP08 in the reproduction of ^{3}He elastic scattering from ^{12}C at 118.5 and 217 MeV [33, 88]. The reason why GDP08 is still reliable for target masses as small as 6 at higher incident energies and its failure at low energies for the 1p-shell nuclei may be

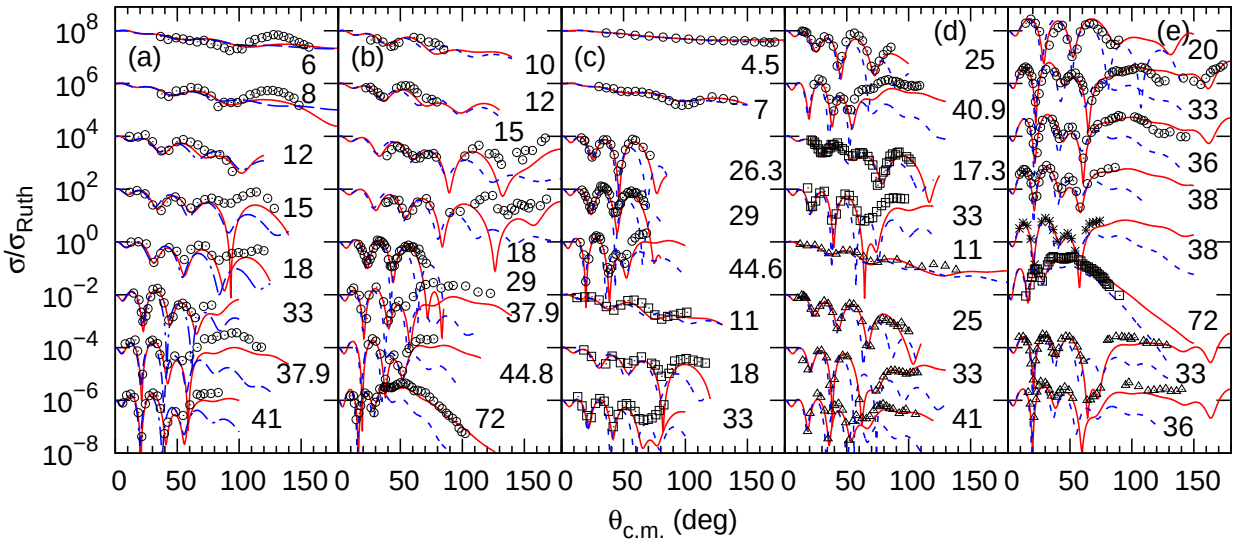

FIG. 3: (Color online) The same as in Fig. 2 but for ^{3}He elastic scattering from targets (a) ^{13}C, (b) ^{14}C, (c) ^{14}N (circles), and ^{15}N (squares), (d) ^{16}O (circles), ^{17}O (squares) and ^{18}O (triangles), and ^{3}H elastic scattering from targets of (e) ^{12}C (circles), ^{13}C (asterisks), ^{14}C (squares) and ^{16}O (triangles).

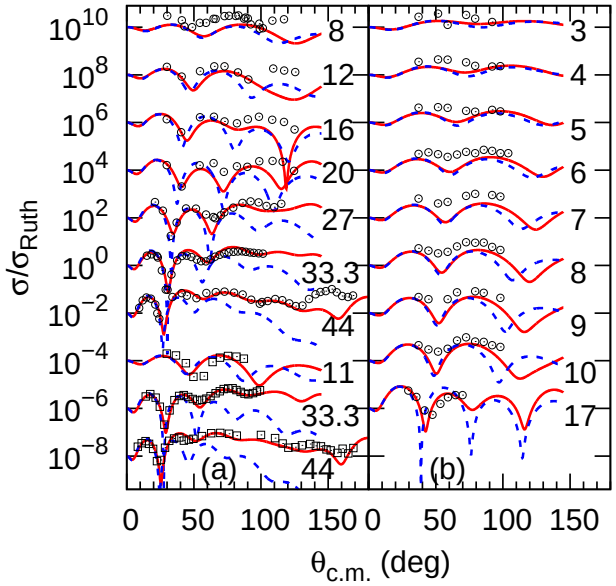

FIG. 4: (Color online) The same as in Fig. 2 but for ^{3}He elastic scattering from targets (a) ^{6}Li (circles) and ^{7}Li (squares), and (b) ^{3}H elastic scattering from ^{6}Li.

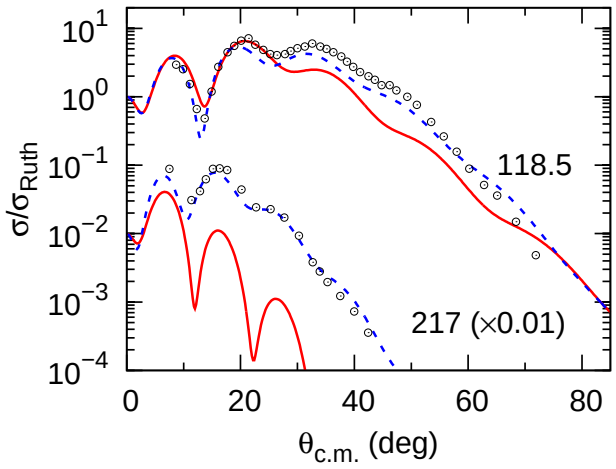

FIG. 5: (Color online) Comparison of the optical model calculations for ^{3}He elastic scattering from ^{12}C at 118.5 and 217 MeV with HT1p (solid curve) and GDP08 (dotted curve). The experimental data are from Refs. [33, 88].

understood from Trost et al. [26]. In Figs. 3 and 4 of Ref.[26], the authors show that the weak target-mass dependence assumed by GDP08 (only through the Coulomb corrections to the incident energies) is satisfied well at high energies. However, the target-mass dependence in the light-target region get stronger as incident energy decreases, what explains the failure of GDP08 at low energies.

B. Volume integrals of the OMPs

Volume integral per interacting nucleon pair of optical model potentials, denoted by $J_{\rm v}$ for the real part and $J_{\rm w}$ for the imaginary part, are important quantities to characterize different systematic potentials. These volume integrals are defined as:

$$\begin{aligned} J_{\rm v}(E) &= \frac{1}{A_{\rm P}A_{\rm T}}\int V(E,r)d\vec{r}, \\ J_{\rm w}(E) &= \frac{1}{A_{\rm P}A_{\rm T}}\int [W_{\rm v}(E,r)+W_{\rm s}(E,r)]d\vec{r}. \end{aligned} \tag{11}$$

$J_{\rm v}$ and $J_{\rm w}$ are supposed to be independent of the projectile and target masses, and are therefore useful to compare different systematic optical potentials. In Fig. 6 we compare the volume integrals of the potentials for ^{3}He impinging on ^{12}C from 1 to 220 MeV evaluated with HT1p and GDP08, respectively. As we discussed above, we estimate that HT1p is applicable for the 1p-shell nuclei below 100 MeV, while GDP08 is applicable at energies

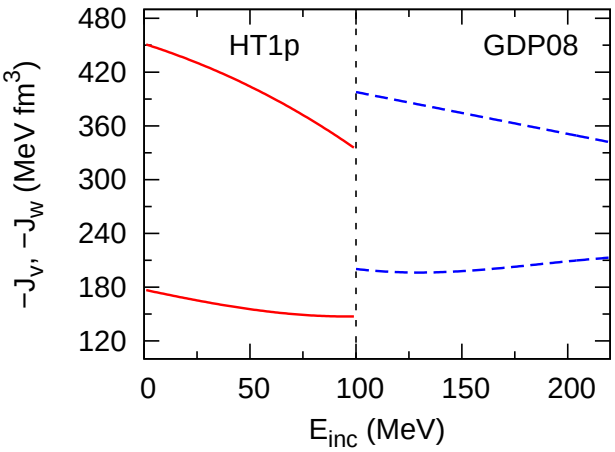

FIG. 6: (Color online) Volume integrals of the optical model potentials HT1p and GDP08 for ^{3}He elastic scattering from ^{12}C from 1 to 220 MeV. The vertical line divides the approximate energy regions in which HT1p and GDP08 are applicable for 1p-shell nuclei. The solid and dashed curves in the upper part of this figure represent the volume integrals of the real potentials of HT1p and GDP08, respectively. The curves in the lower part are for the corresponding imaginary potentials.

higher than this. Clearly, at energies around 100 MeV, there are abrupt differences in $J_{\rm v}$ and $J_{\rm w}$ between HT1p and GDP08. It indicates that new parameterization of the systematic potential should be made for the intermediate energy region to reconcile these two SOMPs, which are established individually in low- and high-energy regions. Experimental data of ^{3}He and ^{3}H elastic scattering from 1p-shell nuclei at $\sim$ 100 MeV are therefore very much needed for such study.

IV. CONCLUSIONS

In conclusion, a set of global optical potential parameters for ^{3}He-nucleus elastic scattering, HT1p, is obtained by simultaneously fitting 118 sets of experimental data of ^{3}He and ^{3}H elastic scattering from 1p-shell nuclei from ^{9}Be to ^{18}O with incident energies from $4 \leqslant E \leqslant 118.5$ MeV and 24 sets of elastic scattering data with the ^{6}Li and ^{7}Li targets from $3 \leqslant E \leqslant 44$ MeV. This new systematic potential is found to be superior to GDP08, which is established for the heavy-target region, in reproduction of the angular distributions of the elastic scattering cross sections of ^{3}He and ^{3}H from 1p-shell nuclei at energies < 100 MeV. At energies above 100 MeV, GDP08 is found to be better than HT1p. Results of this paper can

pave the way to unify these two systematic potentials for a SOMP describing ^{3}He-nucleus elastic scattering in broad interval of energies.

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