In this paper, we construct a new phenomenological isospin dependent global neutron-nucleus optical model potential. Based on the existing experimental data of elastic scattering angular distributions for neutron as projectile, we obtain a set of the isospin dependent global neutron-nucleus optical model potential parameters, which can basically reproduce the experimental data for target nuclei from $^{24}\text{Mg}$ to $^{242}\text{Pu}$ with the energy region up to 200 MeV.
I. INTRODUCTION

The optical model (OM) is of fundamental importance on many aspects of nuclear physics [1]. It is the basis and starting point for many nuclear model calculations and also is one of the most important theoretical approaches in nuclear data evaluations and analyses. The optical model potential (OMP) parameters are the key to reproduce the experimental data, such as reaction cross sections, elastic scattering angle distributions, and so on.

Over the past years, a number of excellent local and global optical potentials for nucleons have been proposed [2][3][4]. Koning and Delarche [2] constructed a set of global phenomenological nucleon-nucleus optical model potential parameters (KD OMP), which can perfectly reproduce the experimental data for the region of targets from $^{24}$Mg to $^{209}$Bi with the incident energy from 1 keV to 200 MeV; Weppner et al [5] obtained a set of isospin dependent global nucleon-nucleus optical model potential parameters (WP OMP) with target nuclei region from carbon to nickel and the projectile energy from 30 to 160 MeV; Han et al [6] also obtained a new set of global phenomenological optical model potential parameters for nucleon-actinide reactions with energies up to 300 MeV. In the nucleon optical model potential, the isospin degree of freedom may play an important role to more accurately describe the experimental data [7][8]. Information on the isospin dependence of the nucleon optical model potential has been shown to be very useful to understand the nuclear symmetry energy [9][12], which encodes the energy related to the neutron-proton asymmetry in the equation of state of isospin asymmetric nuclear matter and is a key quantity for many issues in nuclear physics and astrophysics (See, e.g., Ref. [13]). On the other hand, to study the systematics of neutron scattering cross sections on various nuclei for neutron energies up to several hundred MeV is a very interesting and important topic due to the concept of an accelerator driven subcritical (ADS) system in which neutrons are produced by bombarding a heavy element target with a high energy proton beam of typically above 1.0 GeV with a current of 10 mA and the ADS system serves a dual purpose of energy multiplication and waste incineration (See, e.g., Ref. [14]). Therefore, to construct a more accurate neutron-nucleus optical model potential is of crucial importance. The motivation of the present paper is to construct a new isospin dependent neutron-nucleus optical model potential, which can reproduce the experimental data for a wider range of target nucleus...
than the formers.

This paper is arranged as follows. In Sec. II, we provide a description of the optical model and the form of the isospin dependent neutron-nucleus optical potential. Section III presents the results, and section IV is devoted to the discussion. Finally, a summary is given in Sec. V.

II. OPTICAL MODEL AND THE FORM OF THE ISOSPIN DEPENDENT NEUTRON-NUCLEUS OPTICAL POTENTIAL

The phenomenological OMP for neutron-nucleus reaction $V(r, E)$ is usually defined as follows:

$$V(r, E) = -V_v f_v(r) - i W_v f_v(r) + i 4 a_s W_s \frac{df_s(r)}{dr} + \lambda^2 \frac{V_{so} + iW_{so}}{r} \frac{df_{so}(r)}{dr} 2\vec{S} \cdot \vec{l},$$  \hspace{1cm} (1)

where $V_v$ and $V_{so}$ are the depth of real part of central potential and spin-orbit potential, respectively; $W_v, W_s$ and $W_{so}$ are the depth of imaginary part of volume absorption potential, surface absorption potential and spin-orbit potential, respectively. The $f_i$ ($i = v, s, so$) are the standard Wood-Saxon shape form factors.

In this work, according to Lane Model [7], we add the isospin dependent terms in the $V_v, W_v$ and $W_s$, which can be parameterized as:

$$V_v = V_0 + V_1 E + V_2 E^2 + (V_3 + V_{3L} E) (N - Z)/A, \hspace{1cm} (2)$$

$$W_s = W_{so} + W_s1 E + (W_{s2} + W_{s2L} E) (N - Z)/A \hspace{1cm} (3)$$

$$W_v = W_{v0} + W_{v1} E + W_{v2} E^2 + (W_{v3} + W_{v3L} E) (N - Z)/A \hspace{1cm} (4)$$

The shape form factors $f_i$ can be expressed as

$$f_i(r) = \left[ 1 + \exp((r - r_i A^{1/3})/a_i) \right]^{-1} \text{ with } i = v, s, so \hspace{1cm} (5)$$

where

$$r_i = r_{i0} + r_{i1} A^{-1/3} \hspace{1cm} \text{ with } i = r, v, s, so \hspace{1cm} (6)$$

$$a_i = a_{i0} + a_{i1} A^{1/3} \hspace{1cm} \text{ with } i = r, v, s, so \hspace{1cm} (7)$$
In above equations, \( A = Z + N \) with \( Z \) and \( N \) being the number of protons and neutrons of the target nucleus, respectively; \( E \) is the incident neutron energy in the laboratory frame; \( \lambda_\pi^2 \) is the Compton wave length of pion, and usually we use \( \lambda_\pi^2 = 2.0 \text{ fm}^2 \).

APMN \[15\] is a code to automatically search for a set of optical potential parameters with smallest \( \chi^2 \) in \( E \leq 300 \text{ MeV} \) energy region by means of the improved steepest descent algorithm \[16\], which is suitable for non-fissile medium-heavy nuclei with the light projectiles, such as neutron, proton, deuteron, triton, \(^3\)He, and \( \alpha \). The optical potential in APMN \[15\] has been modified based on the standard BG form \[3\], i.e. Woods-Saxon form for the real part potential \( V_r \) and the imaginary part potential of volume absorption \( W_v \); derivative Woods-Saxon form for the imaginary part potential of surface absorption \( W_s \); and Thomas form for the spin-orbital coupling potential \( V_{so} \) and \( W_{so} \). It should be noted that all the radius and diffusiveness parameters in the standard BG optical potential form are constant, not varying with the mass of target nuclei. In the present work, they are modified as functions of the mass of target nuclei according to our former work \[17\]. We modify the APMN code according to the the present form of the isospin dependent global neutron-nucleus optical model potential and thus totally 32 adjustable parameters are involved in the code APMN \[15\].

In the code APMN \[15\], the compound nucleus elastic scattering is calculated with the Hauser-Feshbach statistic theory with Lane-Lynn width fluctuation correction \[18\] (WHF), which is designed for medium-heavy target nuclei. For these nuclei, the spaces between levels are usually small, the concepts of continuous levels and level density can be properly used for description of higher levels, say, their excited energies are higher than the combined energy of the emitting particle in compound nucleus. In the code APMN, the Hauser-Feshbach theory supposed that after the compound nucleus emits one of the six particles–n, p, d, t, \( \alpha \) and \(^3\)He, or a \( \gamma \) photon, all discrete levels of the residual nucleus de-excite only through emission of \( \gamma \) photons, not permitting emission of any particles. For medium-heavy target nuclei, when the incident energy increase to about 5–7 MeV, the cross sections of the compound nucleus elastic scattering usually will drop to very small values in comparison with the shape elastic scattering; so there is no need for considering pre-equilibrium particle emission.
III. RESULTS

Our theoretical calculation is carried out within the non-relativistic frame and the relativistic kinetics corrections have been neglected because they are usually very small when the projectile energy $E \leq 200$ MeV (See, e.g., Ref. [19]). In the present work, we choose the existing experimental data of neutron elastic scattering angular distributions with the incident energy region from 0.134 to 225 MeV for the 45 target nuclei shown in Table I as the data base, for searching for global neutron optical potential parameters. These data shown in Table I have been also used in the work of Koning and Delarche [2]. In this work, all of experimental data used are taken from EXFOR (web address: http://www.nndc.bnl.gov/). As for the data error, we take the values given in EXFOR if they are available (we note here that more than 90% data considered in the present work have data error in EXFOR); in the case that the data errors are not provided in EXFOR, we take them as 10% of the corresponding experimental data, which roughly corresponds to the mean value of the available experimental data error.

We use the global neutron optical model potential parameters of Becchetti and Greenless [3] as starting point. The value of zero has been used as the initial values for the parameters that we add newly in the code APMN.

Through the calculation of APMN code, we obtain a new set of isospin dependent global neutron-nucleus optical model potential parameters which can be expressed as following:

$$V_v = 54.983 - 0.3278E + 0.00031E^2 - (18.495 - 0.219E)(N - Z)/A \text{ (MeV)}$$  \hspace{1cm} (8)$$

$$W_s = 11.846 - 0.182E - (16.66 - 0.0141E)(N - Z)/A \text{ (MeV)}$$  \hspace{1cm} (9)$$

$$W_v = -2.5028 + 0.2144E - 0.00126E^2 - (0.000248 - 0.2139E)(N - Z)/A \text{ (MeV)}$$  \hspace{1cm} (10)$$

$$a_r = 0.696 - 0.00064A^{1/3} \text{ (fm)}, \quad a_s = 0.563 - 0.0137A^{1/3} \text{ (fm)}$$  \hspace{1cm} (11)$$

$$a_v = 0.912 + 0.0539A^{1/3} \text{ (fm)}, \quad a_{so} = 0.677 + 0.0203A^{1/3} \text{ (fm)}$$  \hspace{1cm} (12)$$

$$r_r = 1.173 - 0.002A^{-1/3} \text{ (fm)}, \quad r_s = 1.278 - 0.014A^{-1/3} \text{ (fm)}$$  \hspace{1cm} (13)$$

$$r_v = 1.266 + 0.02A^{-1/3} \text{ (fm)}, \quad r_{so} = 0.828 + 0.01A^{-1/3} \text{ (fm)}$$  \hspace{1cm} (14)$$

$$V_{so} = 8.797 \text{ (MeV)}, \quad W_{so} = 0.019 \text{ (MeV)}$$  \hspace{1cm} (15)$$
where the unit of the incident neutron energy $E$ is MeV.

With above optical model potential parameters, we calculate the angular distributions of elastic scattering for many nuclei with neutron as projectile. Some of the calculated results and experimental data of elastic scattering angular distributions are shown in Fig. 1 to Fig. 12 where the corresponding results from KD OMP are also included for comparison.

IV. DISCUSSION

The $\chi^2$ represents the deviation of the calculated values from the experimental data, and in this work it is defined as follows:

$$\chi^2 = \frac{1}{N} \sum_{n=1}^{N} \chi_n^2,$$

where $\chi_n^2$ is for a single nucleus, and $n$ is the nucleus sequence number. $\chi^2$ is the average values of the $N$ nuclei with $N$ denoting the numbers of nuclei included in global parameters search and its value is 45 in the present work. $\sigma_{el}^{th}(i, j)$ and $\sigma_{el}^{exp}(i, j)$ are the theoretical and experimental differential cross sections at the $j$-th angle with the $i$-th incidence energy, respectively. $\Delta\sigma_{el}^{exp}(i, j)$ is the corresponding experimental data error. $N_{n,i}$ is the number of angles for the $n$-th nucleus and the $i$-th incidence energy. $N_{n,el}$ is the number of incident energy points of elastic scattering angular distribution for the $n$-th nucleus.

Through minimizing the average $\chi^2$ value for the 45 nuclei in Table I with the modified code APMN, we find an optimal set of global neutron potential parameters, which are given in Eqs. (8)–(15). With the obtained parameters above, we get the average value of $\chi^2 = 32.27$ for the 45 nuclei. Using the parameters of Koning and Delaroche [2], we obtain the average value of $\chi^2 = 30.11$ for the same 45 nuclei. Therefore, our parameter set has almost the same good global quality as that of Koning and Delaroche for the global neutron potential.

We use the optical model potential parameters of ours and Koning et al to calculate the $\chi_n^2$ of a single nucleus for the 45 nuclei in Table I. In addition, in order to see the predictive power, we also calculate the $\chi_n^2$ for other 58 nuclei listed Table II where the incident energy region and references are also given. The calculated results for all the 103 nuclei in Table I
and Table II are shown in Table III where our results are denoted by $\chi_{n1}^2$ and that of Koning et al are denoted by $\chi_{n2}^2$, respectively.

From Table III, we can see that the value of $\chi_{n1}^2$ is close to that of $\chi_{n2}^2$ for the nuclei in Table I; The value of $\chi_{n1}^2$ is much less than that of $\chi_{n2}^2$ for the nuclides Os, Pt, Th, U, and Pu; The value of $\chi_{n1}^2$ is also close to that of $\chi_{n2}^2$ for the other nuclei. This means that our new set of the isospin dependent global neutron-nucleus optical potential parameters can be as equally good as that of Koning et al to reproduce the experimental data for neutron as projectile with target ranging from $^{24}$Mg to $^{209}$Bi. However our results are better than those of Koning et al for the actinide. We would like to point out that the number of parameters of our optical model potential is significantly less than that of Koning et al.

Some of the elastic scattering angular distributions obtained with our global optical potential parameters and with those of Koning et al as well as the corresponding experimental data are plotted in Figs. 1 to 12. The solid lines are the results calculated with our parameters, the dashed lines are the results with the parameters of Koning et al, and the points represent the experimental data. The same symbols are used in all figures. The experimental data and the corresponding theoretical calculation results in all figures are in the center of mass (C.M.) system. From these figures, we can see clearly that our theoretical calculations can reproduce the experimental data as equally well as those of Koning et al in the targets range from $^{24}$Mg to $^{209}$Bi, except for some energy points of few nuclei.

From Fig. 1 and Fig. 2, it is seen that both of our theoretical calculations and those of Koning et al can not well reproduce the experimental data for some energy points of targets $^{40}$Ca and $^{48}$Ca. This is a well-known problem [20][21] for $^{40}$Ca. It may be due to the fact that both $^{40}$Ca and $^{48}$Ca are double magic nuclei and the shell effect corrections may be important. However, both of our work and that of Koning et al aim at constructing global spherical optical model potentials. So the shell effects are not included in both of the OMPs. In addition, the effects of giant resonances have been neglected in both theoretical calculations and including them could improve the agreement [22].

From Figs. 3-8, one can see that there exist some obvious deviations between experimental data and theoretical calculations with both our OMP parameters and that of Koning et al for nuclei Ba and W. This may be due to the fact that the Ba and W exist large deformation, and an effective spherical mean field may no longer provide a totally adequate description of the neutron-nucleus many body problem [2]. Both of the OMPs are based on spherical
frame and the effects of deformation are not considered.

For the actinide, such as Th, U, and Pu, it is seen from Figs. 9-12 that our theoretical results exhibit significantly better agreement with experimental data than those of Koning et al.

V. SUMMARY

A new set of isospin dependent global neutron-nucleus optical potential parameters has been obtained based on the existing experimental data of neutron elastic scattering angular distributions by using the modified code APMN \cite{15}. The calculated elastic scattering angular distributions with the new optical model potential parameters have been shown to be in good agreement with the corresponding experimental data for many nuclei from \(^{24}\)Mg to \(^{242}\)Pu in the energy region up to 200 MeV. In particular, our new global optical model potential parameters can give a significantly improved description of neutron elastic scattering angular distributions for the actinide, such as Th, U, and Pu, than the existing global optical model potential parameters in the literature. Our new global optical model potential can be used to calculate the neutron elastic scattering for different target nuclei including those for which the experimental data are unavailable so far.

In the present work, polarization of the projectile is not considered. The polarized neutron beams may play a very important role in nuclear reaction and nuclear structure studies as well as many fundamental issues of particle physics. We plan to investigate the effect of neutron polarization in a future work.

Acknowledgments

The authors would like to thank Professor Chong-Hai Cai for useful discussions. This work was supported in part by the NNSF of China under Grant Nos. 10975097 and 11047157, Shanghai Rising-Star Program under Grant No. 11QH1401100, and the National Basic
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| nucleus | En.(MeV) | Refs. | nucleus | En.(MeV) | Refs. |
|---------|----------|-------|---------|----------|-------|
| $^{24}\text{Mg}$ | 1.5-14.83 | $[23]-[27]$ | $^{27}\text{Al}$ | 0.3-26 | $[23][28]-[48]$ |
| $^{28}\text{Si}$ | 3.4-21.7 | $[25][27][38][41][49][54]$ | $^{31}\text{P}$ | 3.4-20 | $[25][35][38][40][55][56]$ |
| $^{32}\text{S}$ | 5.95-21.7 | $[26][27][38][54][57][60]$ | $^{40}\text{Ca}$ | 1.175-225 | $[61]-[65]$ |
| $^{45}\text{Sc}$ | 1.6-10 | $[66]$ | $^{51}\text{V}$ | 1.61-14.37 | $[67]-[72]$ |
| $^{52}\text{Cr}$ | 1.5-18.54 | $[73]-[77]$ | $^{55}\text{Mn}$ | 2.47-14.1 | $[25][32][34][72][78]$ |
| $^{54}\text{Fe}$ | 1.3-26 | $[79]-[86]$ | $^{56}\text{Fe}$ | 1.8-26 | $[25][81][83]-[85][87]-[89]$ |
| $^{59}\text{Co}$ | 1-23 | $[32][45][47][78][90]-[95]$ | $^{58}\text{Ni}$ | 1.42-24 | $[73][85][86][96]-[100]$ |
| $^{60}\text{Ni}$ | 1.5-24 | $[73][85][98]-[103]$ | $^{63}\text{Cu}$ | 5.5-13.92 | $[83][104]$ |
| $^{65}\text{Cu}$ | 2.33-13.92 | $[83][88][104]$ | $^{75}\text{As}$ | 3.2-8.05 | $[34][105][106]$ |
| $^{80}\text{Se}$ | 0.34-10 | $[107]-[111]$ | $^{88}\text{Sr}$ | 11 | $[112]$ |
| $^{89}\text{Y}$ | 0.8892-21.6 | $[44][47][113]-[120]$ | $^{90}\text{Zr}$ | 1.5-24 | $[121]-[127]$ |
| $^{91}\text{Zr}$ | 8-24 | $[127]$ | $^{92}\text{Zr}$ | 1.5-24 | $[121][122][124][126][127]$ |
| $^{94}\text{Zr}$ | 1.5-24 | $[121][127]$ | $^{93}\text{Nb}$ | 1-20 | $[44][78][90][128]-[140]$ |
| $^{92}\text{Mo}$ | 0.9-26 | $[121][124][141]-[145]$ | $^{96}\text{Mo}$ | 0.9-26 | $[121][124][141][142][144]-[146]$ |
| $^{98}\text{Mo}$ | 0.9-26 | $[141][142][145]$ | $^{100}\text{Mo}$ | 0.9-26 | $[124][141][142][144][145]$ |
| $^{103}\text{Rh}$ | 1.5-9.995 | $[115][117][147]$ | $^{107}\text{Ag}$ | 1.5-4 | $[148]$ |
| $^{116}\text{Sn}$ | 0.4-24 | $[149]-[151]$ | $^{118}\text{Sn}$ | 0.8-24 | $[149][151]-[153]$ |
| $^{120}\text{Sn}$ | 0.4-16.905 | $[78][149]-[151][154]$ | $^{124}\text{Sn}$ | 0.4-24 | $[149][151]$ |
| $^{127}\text{I}$ | 0.8893-16.1 | $[152][155]-[157]$ | $^{141}\text{Pr}$ | 0.8788-8 | $[34][155][158]-[162]$ |
| $^{142}\text{Nd}$ | 2.5-7 | $[163][164]$ | $^{144}\text{Nd}$ | 2.5-7 | $[163][164]$ |
| $^{148}\text{Sm}$ | 2.47-7 | $[165]-[167]$ | $^{197}\text{Au}$ | 0.134-14.7 | $[44][134][161][168]-[174]$ |
| $^{206}\text{Pb}$ | 0.5-21.6 | $[47][78][161][169][174]-[178]$ | $^{208}\text{Pb}$ | 1.285-225 | $[44][65][178]-[189]$ |
| $^{209}\text{Bi}$ | 2-24 | $[47][182][190]-[194]$ |
TABLE II: The incident energy points and data references of the other 58 nuclei.

| nucleus | En.(MeV) | Refs. | nucleus | En.(MeV) | Refs. |
|---------|----------|-------|---------|----------|-------|
| $^{26}$Mg | 24 | [195] | $^{34}$S | 21.7,25.5 | [54] |
| $^{39}$K | 14.07 | [49] | $^{48}$Ca | 2.35-7.97 | [196] |
| $^{48}$K | 2.9 | [74] | $^{50}$Cr | 1.5-3 | [73] |
| $^{54}$Cr | 1.5-3 | [74][198] | $^{62}$Ni | 1.5-5 | [73][98][152] |
| $^{64}$Ni | 1.5-7 | [73][98] | $^{64}$Zn | 1.5-3 | [73][198] |
| $^{66}$Zn | 1.5-3 | [73][198] | $^{68}$Zn | 1.5-3 | [73] |
| $^{76}$Se | 0.34-10 | [107]-[109][111][199] | $^{78}$Se | 0.34-8 | [107]-[109][199] |
| $^{82}$Se | 0.34-10 | [107]-[109][199] | $^{94}$Mo | 0.9-8.04 | [121][124][141][143][144][146] |
| $^{110}$Cd | 0.4-1.24 | [149] | $^{114}$Cd | 4 | [152] |
| $^{116}$Cd | 0.6-1.24 | [149] | $^{113}$In | 5.19-8.53 | [200] |
| $^{115}$In | 1.8-8.53 | [152][200][201] | $^{122}$Sn | 0.4-11 | [149][151] |
| $^{122}$Te | 0.3-1.97 | [202] | $^{124}$Te | 0.3-1.97 | [202] |
| $^{126}$Te | 0.3-1.97 | [202] | $^{128}$Te | 0.3-1.97 | [202] |
| $^{130}$Te | 0.3-1.97 | [202] | $^{133}$Cs | 0.8772 | [155] |
| $^{134}$Ba | 3-20 | [203] | $^{135}$Ba | 2-20 | [203] |
| $^{136}$Ba | 4-20 | [203] | $^{137}$Ba | 3-20 | [203] |
| $^{138}$Ba | 5-20 | [203] | $^{137}$Ba | 3-20 | [203] |
| $^{138}$Ba | 5-20 | [203] | $^{139}$La | 0.98-8 | [158][162] |
| $^{140}$Ce | 7.5-14.6 | [44][204] | $^{139}$La | 7.5 | [204] |
| $^{146}$Nd | 2.5-7 | [163][164] | $^{148}$Nd | 2.5-7 | [163][164] |
| $^{150}$Nd | 2.5-7 | [163][164] | $^{150}$Sm | 2.47-7 | [165][167] |
| $^{152}$Sm | 2.5-7 | [165][167] | $^{154}$Sm | 6.25-7 | [166][167] |
| $^{152}$Sm | 2.5-7 | [165][167] | $^{181}$Ta | 0.323-14.8 | [44][78][138][205][208] |
| $^{182}$W | 1.5-4.87 | [209][210] | $^{184}$W | 1.5-4.84 | [209][210] |
| $^{182}$W | 1.5-4.87 | [209][210] | $^{184}$W | 1.5-4.84 | [209][210] |
| $^{186}$W | 1.5-3.95 | [209] | $^{190}$Os | 2.5-4 | [211] |
| $^{192}$Os | 1.6-3.94 | [212] | $^{194}$Pt | 2.5-4.55 | [213][214] |
| $^{196}$Pt | 2.53-4.64 | [211] | $^{204}$Pb | 2.53-8 | [176] |
| $^{207}$Pb | 0.5-13.7 | [169][215][178][216] | $^{232}$Th | 0.144-14.1 | [90][181][217][222] |
| $^{233}$U | 0.7-1.5 | [181] | $^{235}$U | 0.185-5.5 | [181][223][226][230] |
| $^{238}$U | 0.055-15 | [181][219][227][236] | $^{239}$Pu | 0.149-14.1 | [181][222][223][237][238] |
TABLE III: $\chi^2_n$ of a single nucleus. $\chi^2_{n1}$ for our global potential parameters, $\chi^2_{n2}$ for those of A. J. Koning and J. P. Delaroche.

| nucleus | $\chi^2_{n1}$ | $\chi^2_{n2}$ | nucleus | $\chi^2_{n1}$ | $\chi^2_{n2}$ | nucleus | $\chi^2_{n1}$ | $\chi^2_{n2}$ |
|---------|---------------|---------------|---------|---------------|---------------|---------|---------------|---------------|
| $^{24}$Mg | 48.07 | 77.88 | $^{26}$Mg | 73.45 | 43.48 | $^{27}$Al | 33.74 | 50.36 |
| $^{28}$Si | 27.24 | 22.88 | $^{31}$P | 33.46 | 43.17 | $^{32}$S | 13.25 | 14.51 |
| $^{34}$S | 18.78 | 15.66 | $^{39}$K | 65.04 | 45.88 | $^{40}$Ca | 19.44 | 16.25 |
| $^{48}$Ca | 319.3 | 301.2 | $^{45}$Sc | 14.08 | 7.934 | $^{48}$Ti | 16.45 | 12.60 |
| $^{51}$V | 29.21 | 21.82 | $^{50}$Cr | 3.095 | 5.057 | $^{52}$Cr | 11.81 | 94.89 |
| $^{54}$Cr | 3.012 | 4.558 | $^{55}$Mn | 17.92 | 23.83 | $^{54}$Fe | 31.20 | 122.7 |
| $^{56}$Fe | 29.40 | 38.53 | $^{59}$Co | 50.25 | 51.38 | $^{58}$Ni | 11.64 | 20.90 |
| $^{60}$Ni | 18.90 | 27.08 | $^{62}$Ni | 6.552 | 9.851 | $^{64}$Ni | 6.625 | 5.580 |
| $^{63}$Cu | 8.719 | 6.573 | $^{65}$Cu | 10.11 | 5.919 | $^{64}$Zn | 6.833 | 7.435 |
| $^{66}$Zn | 6.611 | 4.363 | $^{68}$Zn | 7.712 | 3.665 | $^{75}$As | 12.06 | 11.64 |
| $^{76}$Se | 44.21 | 63.26 | $^{78}$Se | 22.08 | 35.32 | $^{80}$Se | 29.91 | 39.48 |
| $^{82}$Se | 13.97 | 14.68 | $^{88}$Sr | 38.11 | 32.66 | $^{89}$Y | 34.55 | 19.09 |
| $^{90}$Zr | 29.93 | 23.97 | $^{91}$Zr | 31.67 | 19.35 | $^{92}$Zr | 13.97 | 6.971 |
| $^{94}$Zr | 13.06 | 12.79 | $^{93}$Nb | 50.10 | 42.60 | $^{92}$Mo | 24.39 | 29.55 |
| $^{94}$Mo | 40.40 | 35.57 | $^{96}$Mo | 101.8 | 170.6 | $^{98}$Mo | 17.66 | 20.94 |
| $^{100}$Mo | 67.80 | 137.1 | $^{103}$Rh | 10.33 | 15.54 | $^{107}$Ag | 8.043 | 42.19 |
| $^{110}$Cd | 4.622 | 6.179 | $^{114}$Cd | 298.4 | 77.41 | $^{113}$In | 5.413 | 5.741 |
| $^{115}$In | 51.65 | 18.74 | $^{116}$Sn | 8.380 | 8.194 | $^{118}$Sn | 11.67 | 13.38 |
| $^{120}$Sn | 28.10 | 17.12 | $^{122}$Sn | 9.091 | 4.693 | $^{124}$Sn | 10.06 | 5.025 |
| $^{122}$Te | 3.090 | 8.610 | $^{124}$Te | 2.177 | 5.716 | $^{126}$Te | 3.471 | 4.347 |
| $^{128}$Te | 9.282 | 3.668 | $^{130}$Te | 13.68 | 4.837 | $^{127}$I | 91.22 | 50.50 |
| $^{133}$Cs | 7.464 | 7.211 | $^{134}$Ba | 897.9 | 726.0 | $^{135}$Ba | 687.2 | 292.9 |
| $^{136}$Ba | 957.7 | 300.9 | $^{137}$Ba | 1221. | 378.3 | $^{138}$Ba | 2055. | 457.7 |
| $^{139}$La | 44.88 | 41.60 | $^{140}$Ce | 44.40 | 13.34 | $^{142}$Ce | 199.8 | 129.7 |
| $^{141}$Pr | 125.2 | 115.1 | $^{142}$Nd | 27.00 | 20.94 | $^{144}$Nd | 12.55 | 8.944 |
| $^{146}$Nd | 14.58 | 22.04 | $^{148}$Nd | 23.58 | 96.56 | $^{150}$Nd | 137.8 | 319.3 |
| $^{148}$Sm | 118.90 | 30.05 | $^{150}$Sm | 18.01 | 87.68 | $^{152}$Sm | 29.60 | 113.2 |
| $^{154}$Sm | 34.01 | 28.10 | $^{181}$Ta | 33.85 | 92.52 | $^{182}$W | 75.12 | 316.4 |
| $^{184}$W | 65.26 | 252.6 | $^{186}$W | 65.85 | 234.4 | $^{190}$Os | 246.5 | 636.7 |
| $^{192}$Os | 96.69 | 323.6 | $^{194}$Pt | 78.25 | 297.1 | $^{196}$Pt | 69.51 | 204.0 |
| $^{197}$Au | 53.09 | 42.39 | $^{204}$Pb | 48.68 | 48.38 | $^{206}$Pb | 48.26 | 34.32 |
| $^{207}$Pb | 41.30 | 9.177 | $^{208}$Pb | 39.23 | 26.93 | $^{209}$Bi | 50.53 | 24.29 |
| $^{232}$Th | 43.23 | 293.5 | $^{233}$U | 77.01 | 241.0 | $^{235}$U | 33.50 | 126.2 |
| $^{238}$U | 119.3 | 551.8 | $^{239}$Pu | 37.75 | 143.5 | $^{240}$Pu | 36.86 | 175.9 |
| $^{242}$Pu | 27.92 | 91.89 |
FIG. 1: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [26]-[27][38]-[40][49]-[61].
FIG. 2: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [61]-[66][196][197].
FIG. 3: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [152]-[157],[202],[203].
FIG. 4: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [202].
FIG. 5: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [202].
FIG. 6: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [34] [44] [155] [158] [164] [203] [204].
FIG. 7: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [44][78][138][163]-[167][205]-[209].
FIG. 8: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [168][169][209]-[214].
FIG. 9: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [44][65][178][182][185][187]-[192].
FIG. 10: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [47][90][181][191][194][217][221].
FIG. 11: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [181]-[231].
FIG. 12: Comparisons of the experimental angular distributions of elastic scattering (dots) with the calculated results from our global potential parameters (red solid lines) and those of A. J. Koning and J. P. Delaroche (black dashed lines) in the center of mass frame. The experimental data are taken from Refs. [181]-[240].