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Re-examination of Energy-Loss Straggling Calculations of Alpha Particles at 5.486 MeV

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We report on an evaluation of energy-loss straggling calculations performed using the LISE++ code and theoretical models. The energy-loss straggling of the alpha particles at 5.486 MeV in Al, Cu, Ag, Tb, Ta, and Au was calculated by using the LISE++ code and the Titeica model. The results of the calculations were compared to the measured data to improve the accuracy of the straggling predictions. The results show that the straggling is increased by the energy loss at a rate of 8.0 keV/%. The uncertainties of the LISE++ and Titeica calculations were reduced to about 15% by adding fitting parameters. We also propose a new semi-empirical formula which well reproduces the measured data with an uncertainty of about 20% for 5.486-MeV alpha particles in the materials used in the research.

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I. INTRODUCTION

Energy loss and energy spread of heavy-ion beams are important factors in the in-flight radioactive-isotope (RI) beam production [1,2] at accelerator facilities and in studies of nuclear reactions in inverse kinematics using the thick gas-target method [3]. To design and set up reaction measurements using the heavy-ion beams, it is obligatory to estimate the beam energy, the materials in the beam line, and the energy uncertainty together with the energy resolution of the detector systems. The energy uncertainty is always expected to be smaller than the required resolution of the measurements. For instance, thin foils are usually equipped as windows of a target gas cell and beam monitors in the in-flight RI beam production [4,5]. In this scenario, the expected energy and energy spread of ion beams strongly depend on the energy loss and energy-loss straggling of the beams in materials of the windows and in the target gas. These two parameters are commonly estimated by using semi-empirical models and computer codes such as LISE++ [6,7] and SRIM [8,9] to optimize necessary thickness of the materials and the beam energy used in real experiments. Notice that without measurements, theoretical models and computer codes are the unique approach for the estimation of such parameters.

Although the energy loss and energy-loss straggling have been early investigated since first nuclear experiments were carried out at accelerator laboratories, their estimations are still very uncertain. The uncertainty

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is caused by many effects which impact on the energy loss distribution of ions inside target materials. For instance, the energy loss estimation based on the Bethe-Bloch formula requires precision of the density correction and the average excited potential of the target material [10], which cannot be well theoretically determined; the models proposed by N. Bohr [11,12], Lindhard and Scharff [13], Bethe and Livingston [14], Yang *et al.* [15], and Titeica [16] for the energy-loss straggling are only valid in specific cases of the energy range or atomic density. Since the computer codes have been developed based on theoretical models or semi-empirical formulae, their computations have a large uncertainty due to limitations of the theories. Obviously, there are discrepancies between theoretical calculations and measured data. Therefore, the improvements of the theoretical models, such as the mentioned semi-empircal formulae [11–16], and computer codes are always necessary for more precise energy loss and energy-loss straggling which are important in the measurements of low-energy reactions.

In this study, we employed available experimental data observed by S. Kumar *et al.* [17] and Sykes *et al.* [18] to evaluate the energy-loss straggling calculations of the LISE++ code and Titeica model. A set of adjusting coefficients was determined to improve the accuracy of such calculations. In particular, we also proposed a semi-empirical formula for the energy-loss straggling of alpha particles at 5.486 MeV in the materials whose atomic numbers are in the range of $Z = 13 - 79$.

The present paper is constructed as follows. The evaluation method including theoretical models and principle of energy-loss straggling measurements is detailed in Section II. The results of the evaluation including the correction of the theoretical calculations and the proposed semi-empirical formula are discussed in Section III. The summary of this study is given in Section IV.

II. EVALUATION METHOD

We employed the LISE++ code and Titeica model to calculate the energy loss and the energy-loss straggling of alpha particles at 5.486 MeV in the Al ($Z = 13$), Cu ($Z = 29$), Ag ($Z = 47$), Tb ($Z = 65$), Ta ($Z = 73$), and Au ($Z = 79$) foils with various thickness. The thickness of the Al, Cu, and Ag foils are extracted based on the energy loss reported by Sykes *et al.* in Ref. [18]. The values of this quantity are listed in Table 1. The energy of the alpha particles emitted by the ^{241}Am source and the thickness of the absorbing materials used in the experiments [17,18] were input into the Titeica formula and LISE++ code to generate the energy-loss straggling.

Notice that the LISE++ program was integrated both Ziegler subroutines [9], ATIMA [19], and the database of stopping power reported by F. Hubert *et al.* [20]. In the energy region of the alpha emitted from the ^{241}Am source (5.486 MeV), the Ziegler subroutine, which is used in the SRIM code, is employed in the LISE++ program. In the LISE++ code, the straggling is calculated by the direct integration implemented in which the thickness of the target is divided into n individual layers with a thickness of Δx and the final energy-loss straggling is determined based on the square-root of the sum of the intermediate energy loss value as [6,7]

$$\Omega = \sqrt{\sum_{i=1}^{n}\left(\frac{dE_i}{dx_i}\right)^2 \Delta x_i}\ , \tag{1}$$

where dE/dx is the individual energy loss in each divided layer. The energy loss is determined based on the Bethe-Bloch formula [21] described as

$$-\frac{dE}{dx} = K\rho\frac{Zz^2}{A\beta^2}\left[\ln\left(\frac{2m\gamma^2v^2E_{\max}}{I^2} - 2\beta^2 - \delta - 2\frac{C}{Z}\right)\right], \tag{2}$$

where $K = 0.1535$ MeVcm^2/g; m is the rest mass of electron; A, ρ and I are the atomic weight, density and the mean excitation potential of the absorbing material, respectively; $E_{\max}$ is the maximum energy transfer in a single collision; z and v are the atomic number and velocity of the projectile, respectively; $\beta = v/c$; $\gamma = \sqrt{1-\beta^2}$; $c = 3 \times 10^8$ m/s; δ and C denote the density and shell correction factors. Obviously, the energy loss complicatedly depends on various parameters which are corrected by experimental data.

In measurements, such as those conducted by S. Kumar *et al.* and Sykes *et al.*, the energy spectra with and without the thin foils are observed to determine the energy loss and energy-loss straggling of the ion particles in target materials. In the spectra, the peak centroids and

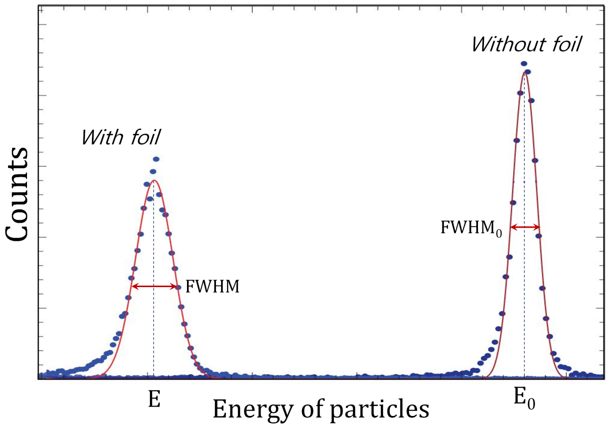

Fig. 1. (Color online) An illustration of the energy spectrum, with and without a thin foil, of particles in energy-loss straggling measurements. The energy loss and energy-loss straggling are determined by the centroids and the widths (FWHM) of the peaks, respectively.

the peak widths ($FWHM$ - Full Width at Half Maximum) are the interests. Figure 1 shows an illustration of the spectra measured in the straggling measurements. The fractional energy loss (or relative energy loss, $\Delta E/E_0$, in %) is deduced by considering the difference between the centroids corresponding to the residual energy (E) after passing through the foils and the incident energy (E_0) of the particles from the source. The energy loss is simply deduced by $\Delta E = E_0 - E$. The energy-loss straggling ($\Omega_{\mathrm{Exp.}}$) is determined by considering the energy spreads in the energy spectra with ($FWHM$) and without ($FWHM_0$) the foils as

$$\Omega^2_{\mathrm{Exp.}} = FWHM^2 - FWHM_0^2 \ , \tag{3}$$

Since the LISE++ straggling is considered by 1σ of the energy spread, it was then converted into $FWHM$, which was obtained in experiments. It should be noted that $FWHM = 2\sqrt{2\ln 2}\sigma$ with the Gaussian distribution. The $FWHM$ values of LISE++ were compared with the measured data and with the results calculated by the Bohr [11,12] and Titeica [16] formulae, which respectively read

$$\Omega^2_B = 4\pi z^2 Z e^4 \rho x \ , \tag{4}$$

where $e = 1.6 \times 10^{-19}$ C and x denotes the thickness of the target, and

$$\Omega^2_{\mathrm{Tit.}} = \Omega^2_B \left[1 + \frac{4}{3}\frac{\varepsilon}{mv^2}\left(\ln\frac{2mv^2}{I} + f(z,v)\right)\right] \ . \tag{5}$$

Notice that the ε and $f(z,v)$ factors in Eq. (5) stand for the average kinetic energy per electron of the target and the Bloch correction function [22], respectively.

Recently, the LISE++ code has been widely used in experiments at accelerator facilities and a large uncertainty has been found in its calculations for the energy-loss straggling as clearly shown in Table 1, we therefore compared the LISE++ results to the measured data to deduce adjusting parameters so that the straggling estimations become more precise. With the same method, we also improve the straggling predictions of the Titeica formula [16] since this formula can give a better results compared to the others such as the Bohr [11,12], Lindhard and Scharff [13], and Bethe-Livingston [14] models.

On the other hand, by considering the dependence of the energy loss and energy-loss straggling on the atomic number (Z), atomic density (ρ), mean excitation energy (I) and the thickness (x) of the target materials together with the behavior of the experimental data, the Bohr and Titeica formulae, we proposed a semi-empirical formula for the straggling of alpha particles at 5.486 MeV in Al, Cu, Ag, Tb, Ta, and Au ($Z = 13 - 79$) materials.

III. RESULTS AND DISCUSSION

The measured and calculated results of the fractional energy loss, the original and the modified energy-loss straggling, and the straggling ratios of the experimental data ($\Omega_{\mathrm{Exp.}}$) to the LISE++ code (Ω_{LISE}) and to the Titeica ($\Omega_{\mathrm{Tit.}}$) estimations corresponding to the materials and thicknesses of the foils are presented in Table 1. We found that there is no significant difference, less than 5.0%, between the LISE++ estimations and the measured data for the energy loss whilst the estimated values are factors of about 1.5 − 3.0 smaller than those observed by S. Kumar *et al* [17] and Sykes *et al.* [18] for the energy-loss straggling. The straggling is drastically increased by the thickness of the targets in measurements and Titeica calculation while LISE++ generates a mild change of this quantity. Figure 2 shows the relation between the energy-loss straggling and the fractional energy loss which is proportional to the thickness of the foils. Notice that the error bars of the Sykes data were assumed to be 15%. As can be seen in Fig. 2, the argument

Table 1. The evaluation of LISE++ and Titeica calculations for energy loss and energy-loss straggling of alpha particles at 5.486 MeV in various foils. The experimental data (Exp. data) are taken from Ref. [18] for Al, Cu, Ag and Ref. [17] for Tb, Ta, Au. The results presented in the ninth and the last columns are the modified LISE++ and Titeica calculations by taking the fitting parameters listed in Table 2.

Foils	mg/cm^2	Exp. data [17,18]		LISE++		Titeica	$\Omega_{\mathrm{Exp.}}/\Omega_{\mathrm{LISE}}$	Mod.LISE	$\Omega_{\mathrm{Exp.}}/\Omega_{\mathrm{Tit.}}$	Mod.Tit.
		$\Delta E/E_0$	Straggling	$\Delta E/E_0$	Straggling	Straggling				
Al	0.20	2	43	2.13	19.49	58.18	2.21	15.62	0.74	0.00
	0.99	11	97	10.75	43.99	128.66	2.21	99.90	0.75	106.22
	2.05	23	176	23.22	65.75	185.20	2.68	174.75	0.95	207.99
	3.08	37	196	36.62	85.15	227.02	2.30	241.49	0.86	283.27
	3.97	50	300	49.69	104.18	257.98	2.88	306.95	1.16	338.99
	4.54	59	365	58.97	118.68	275.84	3.08	356.83	1.32	371.14
	4.85	64	396	64.38	127.82	285.04	3.10	388.27	1.39	347.70
	5.31	73	429	73.11	143.08	298.22	3.00	440.77	1.44	411.43
	6.23	93	542	93.02	165.31	322.96	3.28	517.24	1.68	455.96
Cu	2.38	19	125	18.65	64.31	194.33	1.94	98.68	0.64	87.41
	3.27	26	128	26.36	77.54	227.89	1.65	136.65	0.56	139.75
	3.97	33	166	32.52	87.51	251.09	1.90	165.26	0.66	175.96
	5.53	48	213	47.50	110.49	296.35	1.93	231.22	0.72	246.56
	6.69	60	262	59.86	129.61	325.95	2.02	286.09	0.80	292.74
	7.92	76	314	75.69	151.37	354.65	2.07	348.54	0.89	337.51
	8.70	85	428	84.74	158.62	371.71	2.70	369.35	1.15	364.11
Ag	0.33	2	60	1.88	22.00	70.74	2.73	33.90	0.85	0.00
	1.55	9	115	9.31	49.45	153.30	2.33	115.43	0.75	123.27
	2.58	16	162	15.99	65.89	197.79	2.46	164.25	0.82	190.44
	4.46	29	204	28.51	89.58	260.05	2.28	234.61	0.78	284.46
	8.95	65	414	65.37	158.71	368.38	2.61	439.93	1.12	448.04
	10.11	77	473	77.39	182.92	391.53	2.59	511.83	1.21	482.99
	10.89	86	598	86.24	186.78	406.35	3.20	523.30	1.47	505.37
Tb	4.20	22	141 $\pm$ 6	22.20	81.39	244.44	1.73	182.78	0.58	132.72
	5.59	29	207 $\pm$ 7	30.20	96.50	282.00	2.15	233.10	0.73	201.12
	8.70	48	319 $\pm$ 9	49.78	130.59	351.81	2.44	346.60	0.91	328.10
	10.93	64	364 $\pm$ 11	65.84	159.23	394.33	2.29	441.94	0.92	405.44
	13.34	85	517$\pm$16	85.82	188.08	435.64	2.75	537.99	1.19	480.58
Ta	4.75	22	185$\pm$7	22.10	85.57	258.24	2.16	196.70	0.72	184.37
	5.63	26	234$\pm$8	26.50	94.44	281.14	2.48	226.26	0.83	222.93
	7.50	36	283$\pm$9	36.21	112.56	324.49	2.51	286.57	0.87	295.91
	11.60	60	416$\pm$9	59.89	154.16	403.55	2.70	425.07	1.03	429.01
	13.40	72	494$\pm$12	71.67	174.30	433.74	2.83	492.12	1.14	479.82
Au	4.65	21	202$\pm$6	20.06	83.79	254.76	2.41	190.77	0.79	213.24
	5.93	27	300$\pm$9	25.98	96.39	287.69	3.11	232.72	1.04	270.22
	8.30	40	358$\pm$10	37.47	118.79	340.36	3.09	307.30	1.05	361.35
	10.72	52	416$\pm$11	50.21	142.99	386.81	2.91	387.87	1.08	441.71
	14.25	74	529$\pm$12	71.48	185.40	445.98	2.85	529.10	1.19	544.08
	16.01	87	616$\pm$19	83.41	195.91	472.71	3.14	564.06	1.30	590.34

between the LISE++ computation and measurements is clearly addressed (left panel) whilst the difference between the Titeica calculation and the experimental data is rather complicated (right panel) even though the Titeica prediction is compatible with the measurements. It was found that the straggling is increased by the relative energy loss ($\Delta E/E$ in %) with average rates of 3.0 keV/%, 6.0 keV/%, and 8.0 keV/% for the LISE++, Titeica, and experimental data, respectively.

The discrepancy between the LISE++ results and measured data is increased by the thickness of the foils. This phenomenon can be understood by the direct integration implemented in the LISE++ code as mentioned in the previous section (Eq. (1)). In this calculation method, the atomic density and the oscillation of the bound classical electrons are assumed to be the same for all the layers. In addition, the energy loss is determined by assuming that the electron density is uniform in the target materials. These assumptions, which are not completely true for the real materials, result in the large discrepancy between the LISE++ calculations and measured data.

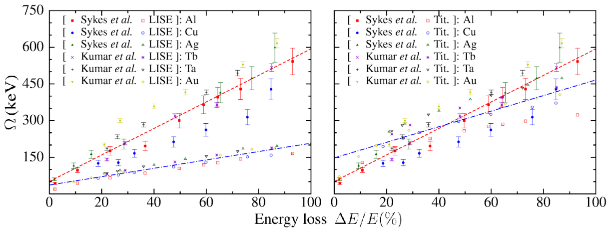

Fig. 2. (Color online) Relations between the energy-loss straggling and the fractional energy loss. The lines are to guide the eyes for the experimental data obtained by S. Kumar *et al.* [17] and Sykes *et al.* [18] (red dashed lines), LISE++ (dotted-dashed line on the left panel), and Titeica (dotted-dashed line on the right panel) calculations. The errors of Sykes data were assumed to be 15%.

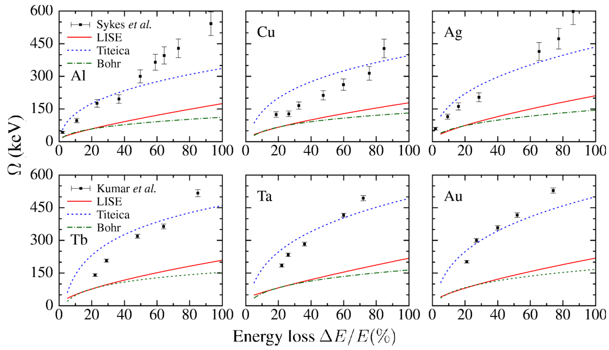

Fig. 3. (Color online) A comparison of the stragglings in Al, Cu, Ag, Tb, Ta, and Au foils computed by LISE++ (solid red curve) with those obtained from Bohr (dotted-dashed green curve), Titeica (dotted blue curve) and experiments [17,18] (black square marks).

For the dependence of the energy-loss straggling on the atomic number of the target materials, the LISE++ and Titeica stragglings are increased by higher-Z absorbers, as shown in Fig. 2. This relation is totally consistent with the theory predicted by N. Bohr [11,12] and easily to be understood by the calculations of the straggling and energy loss described in Eq. (1, 2), and Bohr formula expressed in Eq. (4), which are directly proportional to the Z-number and thickness of the targets. In contrast, the experimental data show a complicated dependence of the straggling on the atomic numbers of the absorbers. For example, although the aluminium has a lower Z-number ($Z = 13$), its straggling is higher than that in copper ($Z = 29$) and compatible with those in silver ($Z = 47$) and terbium ($Z = 65$) as can be seen in Fig. 2. This phenomenon may be caused by the difference of the electron density of the target materials. On the other hand, both the LISE++, Titeica calculations and experiments show that the dependence of the straggling on the energy loss follows a non-linear relationship and the magnitudes of the LISE++ results are much smaller than the Titeica estimation and those observed by S. Kumar *et al.* [17] and Sykes *et al.* [18]. This non-linearity can be understood by taking into account the theories of the energy-loss straggling proposed by N. Bohr [11,12], Lindhard and Scharff [13], Bethe and Livingston [14], Yang *et al.* [15], Titeica [16], and the energy loss description (Eq. (2)). The difference of the magnitudes should be explained by the uncertainty of the mean ionization potential due to the deviations of the energy level of subshells, number of electrons, Bloch correction, and the binding energy of the ionization electrons in the target materials. This phenomenon was well addressed by the previous studies [17,21,23,24].

Figure 3 shows a comparison of the energy-loss straggling determined by the LISE++ code, Bohr [11,12], and Titeica [16] theories and the experimental data. It was found that the Titeica calculation is compatible with the experimental data and much higher than the LISE++ results, which are almost similar to those obtained by Bohr theory. Obviously, there are discrepancies between the measured values and the calculations but the LISE++ code is less appropriate compared with Titeica formula in the energy-loss straggling prediction. The discrepancies between the LISE++ and Titeica predictions and experimental data lead to the need of improvements for the calculations.

In order to improve the accuracy of the straggling calculations using the LISE++ code and Titeica model, we normalized the LISE++ (Ω_{LISE}) and Titeica ($\Omega_{\mathrm{Tit.}}$) estimations with the measured data ($\Omega_{\mathrm{Exp.}}$) by using the relations as follows

$$\begin{aligned} \Omega_{\mathrm{Exp.}} &= a_1 \times \Omega_{\mathrm{LISE}} + b_1 \ , \\ \Omega_{\mathrm{Exp.}} &= a_2 \times \Omega_{\mathrm{Tit.}} + b_2 \end{aligned} \tag{6}$$

where a_i and b_i ($i = 1, 2$) are the linear fitting parameters.

The results of the normalization are shown in Fig. 4 with the fitting parameters listed in Table 2. It is shown that, by using these supplemental parameters, the estimations shift towards the experimental data with an average discrepancy about 15%, as presented in Table 1.

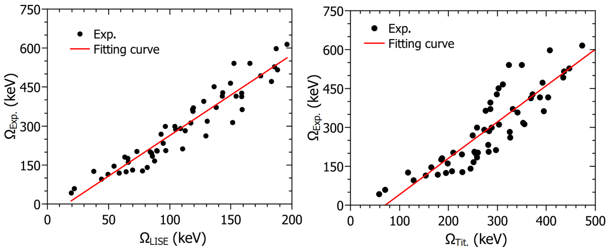

Fig. 4. (Color online) The normalization of the LISE++ calculation based on the results generated by Titeica's formula and the experimental data for all foils. The red lines are the linear fits associated with the fitting parameters presented in the last row of Table 2.

Subsequently, the relations in Eq. (6) together with their coefficients are useful tools for better straggling predictions based on the LISE++ code and Titeica formula. In other words, the modification adding to the LISE++ and Titeica calculations can provide more precise estimations of the energy-loss straggling of alpha particles at $E = 5.486$ MeV in the materials of interest.

Taking the experimental data together with the form of the Titeica model in Eq. (5), we propose that the energy-loss straggling of a particle in materials can be described by a semi-empirical formula in terms of the thickness (x) and atomic number (Z) of the target materials as

$$\ln\Omega = a\ln^2(\eta) + b\ln(\eta) + c\ , \tag{7}$$

where $\eta = \frac{x}{Z^{1/3}}$; a, b, and c are the fitting parameters deduced by using the experimental data. This relation is proposed based on the dependences of the Bohr straggling (Eq. (4)) and the mean excitation energy I on Z-number of targets [21] together with the form of the Titeica model. The straggling (Ω) and thickness (x) in the mentioned formulae are in the units of keV and $mg.cm^{-2}$, respectively. By using the experimental data obtained by S. Kumar *et al.* [17] and Sykes *et al.* [18] we determined the coefficients of the aforementioned straggling function for the alpha particles at 5.486 MeV in Al, Cu, Ag, Tb, Ta, and Au ($Z = 13-79$) materials as follows

$$\begin{aligned} a &= 0.114 \pm 0.025\ , \\ b &= 0.778 \pm 0.036\ , \\ c &= 5.209 \pm 0.035\ . \end{aligned} \tag{8}$$

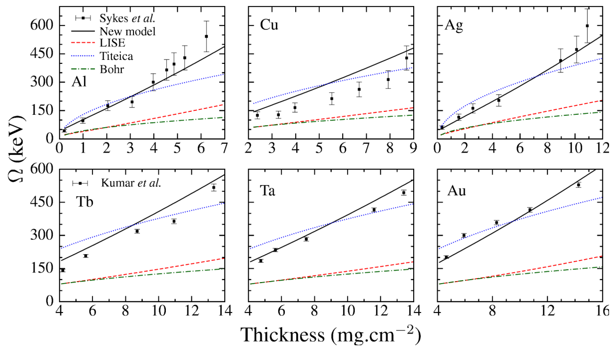

Fig. 5. (Color online) A comparison between the new semi-empirical model (Eq. (7)), the other calculations and the measured data [17,18]. The results estimated by the new model (solid curve) shift toward the experimental data (black square marks) with an average difference less than 20%.

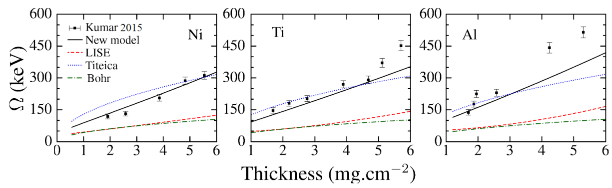

Fig. 6. (Color online) The validation results of the new model (solid curve) for stragglings of the alpha aparticles at 5.486 MeV in Ni, Ti, and Al. The calculations of the new formula are compared to measured data published in Ref. [23] (black square marks) and those estimated by LISE, Bohr, and Titeica computations.

The comparison of the straggling calculated by the proposed model to the experimental data and those calculated by the LISE code, Bohr, and Titeica models is shown in Fig. 5. The results show that the semi-empirical formula can generate the better results rather than the Titeica model. In other words, the uncertainty in the prediction of the energy-loss straggling of the alpha particles at 5.486 MeV in the materials with $Z = 13-79$ is drastically reduced by using the model proposed the present study. The typical discrepancy between the new semi-empirical formula and experimental data is about 20% while it is about 45% for the Titeica model. Obviously, the proposed model much enhances the accuracy of the straggling compared to the LISE, Bohr, and Titeica calculations.

To validate the proposed semi-empirical formula, the measurements which provide experimental information such as various thicknesses and materials of absorbers are necessary. Unfortunately, such data are either very limited or large uncertainty. Therefore, we tried to employ the most available measured data of the straggling

Table 2. The coefficients in the relation of Eq. (6) were obtained by linear fitting of the LISE++ and Titeica results based on the experimental data observed by S. Kumar *et al.* [17] and Sykes *et al.* [18].

Foils	a_1	b_1	a_2	b_2
Al	3.44 ± 0.17	-51.43 ± 18.41	1.80 ± 0.22	-125.37 ± 54.83
Cu	2.87 ± 0.39	-85.89 ± 46.13	1.56 ± 0.31	-215.75 ± 73.79
Ag	2.97 ± 0.26	-31.44 ± 32.62	1.51 ± 0.23	-108.22 ± 55.92
Tb	3.28 ± 0.30	-120.54 ± 41.52	1.82 ± 0.31	-311.84 ± 64.74
Ta	3.34 ± 0.28	-92.924 ± 15.33	1.68 ± 0.39	-250.37 ± 47.32
Au	3.23 ± 0.24	-39.49 ± 39.99	1.73 ± 0.28	-227.55 ± 46.71
All	3.12 ± 0.14	-48.79 ± 16.84	1.40 ± 0.11	-99.37 ± 58.91

in Ni ($Z = 28$), Ti ($Z = 22$), and Al ($Z = 13$) obtained in another work conducted by S. Kumar *et al.* in 2015 [23] to evaluate the new formula in Eq. (7). The results of the validation show that the new model well reproduced the experimental data, especially for Ni and Ti foils, and it is better than the Titeica model in use as shown in Fig. 6. Notice that there are large discrepancies between the data for Al foils measured by S. Kumar *et al.* in 2015 [23] and Sykes *et al.* [18]. These discrepancies result in the uncertainty of the straggling predicted by the new semi-empirical model. Therefore, taking the present study together with the experimental data, we suggest that new measurements for the straggling of alpha particles in Al foils should be performed to confirm the two mentioned different results. In general, the results of the validation indicate that the semi-empirical model calculations are in a good agreement with the experimental data. It is also found that although the new model gives a better results, it is simpler to be used rather than that proposed by Titeica since it does not require complicated calculations for the Bloch correction ($f(z, v)$) and average kinetic energy per electron (ε) of the absorbers, as described in Eq. (5).

It should be noted that the model in this study is proposed for the alpha particles at 5.486 MeV in materials with the atomic numbers $Z = 13 - 79$. Since the energy-loss straggling strongly depends on the incident energy, atomic numbers of the projectiles and absorbers, we could not carry out further development for the proposed semi-empirical formula due to lack of experimental data. In such scenario, more measurements of various projectiles at different energies in other targets are highly demanded to improve the new model in future.

IV. CONCLUSION

We found that there is a large discrepancy between the calculations using the LISE++ code, Bohr model, Titeica formula, and practical values of the energy-loss straggling of alpha particles at 5.486 MeV in Al, Cu, Ag, Tb, Ta, and Au materials. The measured straggling and Titecia results are compatible to each other and much larger than those calculated by the LISE++ code and Bohr model. Since the LISE++ code is widely used in nuclear experiments and the Titeica calculation is better than the others, we drastically reduced the uncertainty of the their calculations by adding the supplemental coefficients obtained from the normalization using the measured data. The modification shows good estimations with a difference less than 15% compared to the experimental data. On the other hand, the results of the new semi-empirical formula are in a good agreement with those obtained in the previous experiments. By considering the smaller uncertainty in calculations and simpler in use, the proposed model in this study is a useful tool for estimating the energy-loss straggling of the alpha particles at 5.486 MeV in the materials with $Z = 13$ - 79. Finally, the present study provides necessary information for the energy-loss straggling calculations using the computer code and theories.

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