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Coefficients of different macro-microscopic mass formulae from the AME2012 atomic mass evaluation

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Abstract

The coefficients of different possible macro-microscopic mass formulae previously proposed have been adjusted on 2264 experimental atomic masses extracted from the AME2012 atomic mass evaluation [1] assuming $N, Z \geq 8$ and the one standard deviation uncertainty on the mass lower than 150 keV. All the formulae include the volume and surface energies, the Coulomb energy, the diffuseness correction to the sharp radius Coulomb energy, the shell and pairing energies and take into account or not the curvature energy, different forms of the Wigner term, a free charge radius, the experimental equivalent rms charge radius or a fixed short central radius. Masses of 976 more exotic nuclei are extrapolated from the most accurate formula.

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Keywords: Macro-microscopic mass formula, liquid drop model, exotic nuclei.

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1 Introduction

The binding energies of exotic nuclei close to the proton and neutron drip lines and in the superheavy element region are still poorly known and the different predictions do not fully agree completely. Therefore continuous efforts are still needed to improve the accuracy of the predictions from mass formulae. Recently, a semiempirical nuclear mass formula based on the macroscopic-microscopic method incorporating the isospin and mass dependence of the parameters and the mirror nuclei constraints have been adjusted on 2149 measured nuclear masses [2,3]. The nuclear mass predictions through the Garvey-Kelson relations have also been improved [4] while the ability of different liquid drop mass formulae and the Duflo-Zuker mass formula to describe the nuclear masses in various deformation regions has been analyzed [5,6].

In a previous paper [7] different formulae including the volume and surface energies, the Coulomb energy, the diffuseness correction to the sharp radius Coulomb energy and the shell and pairing energies and taking into account or not the curvature energy, different forms of the Wigner term, a free charge radius, the experimental equivalent rms charge radius or a fixed short central radius have been proposed. Their coefficients were adjusted on a mass data set of 2027 nuclei verifying the two conditions : $N, Z \geq 8$ and the one standard deviation mass uncertainty ≤ 150 keV. The data were extracted from the 2003 atomic mass evaluation [8]. In the present paper, the same procedure has been applied using the updated AME2012 atomic mass evaluation [1]. The coefficients of these formulae have been adjusted on 2264 masses. One of these expressions leads to a rms deviation between the theoretical and experimental masses of 0.59 MeV. In a second part, the masses of 976 other nuclei appearing in the AME2012 but known with an higher uncertainty or extrapolated have been compared with the values calculated with this formula.

2 Macro-microscopic binding energy

The binding energy has been calculated using the following expansion in powers of $A^{-1/3}$ and $I = (N - Z)/A$:

$$B = a_v (1 - k_v I^2) A - a_s (1 - k_s I^2) A^{2/3} - a_k (1 - k_k I^2) A^{1/3} - \frac{3 e^2 Z^2}{5 R_0} + f_p \frac{Z^2}{A} - E_{pair} - E_{shell} - E_{Wigner}. \quad (1)$$

The first term gives the volume energy. It incorporates the symmetry energy term of the Bethe-Weizsäcker mass formula. The second and third terms represent the surface and curvature energies. They depend also on the relative neutron excess or lack. The decrease of binding energy due to the Coulomb repulsion is given by the fourth term. Different charge radii will be assumed. The Z^2/A term is the diffuseness correction to the sharp radius Coulomb energy (also called proton form-factor correction). The shell energies of the Thomas-Fermi model [9,10] have been retained. They have been calculated from the Strutinsky shell-correction method and previously to the other coefficients of the TF model. As an example, the shell effects add 11.55 MeV to the binding energy of ^{132}Sn . It has been shown [11] that there is no correlation between the pairing term and any other term and, consequently, the pairing term of the TF model has been also retained. The Wigner energy depends on the number of identical neutron-proton pairs in the nucleus and then on I . The origin and meaning of this term are described in Ref. [12]. The binding energy is lower when $N \neq Z$. Three expressions of the Wigner term have been considered: the original linear version $k_1|I|$ and two terms proposed in [13,14] $k_2|N - Z| \times e^{-(A/50)^2}$ and $k_3e^{-80I^2}$ with different coefficients. The second term is characteristic of Wigner's supermultiplet theory based on SU(4) spin-isospin symmetry while the third term represents the n-p pairing at T=0 [14].

3 Coefficients of different mass formulae

The coefficients of different possible mass formulae have been obtained by a least square fitting procedure on the masses of the 2264 nuclei given in the new AME2012 atomic mass evaluation [1] and verifying the two conditions : N and Z higher than 7 and the one standard deviation uncertainty on the mass lower than 150 keV. They are given in the Table 1.

The equations (1-5) in the table have been obtained assuming the linear approximation $R_0 = r_0 * A^{1/3}$, the reduced radius r_0 and the other coefficients being given by the adjustment to the experimental masses. The rms deviations are given in the last column. The curvature term depending on two parameters is less efficient than the Wigner term which depends on only one parameter. The different Wigner terms lead to higher values of r_0 . The combination of two Wigner terms allows to reach an accuracy of 0.588 MeV. The combination of the three Wigner terms would lead to a rms deviation of 0.584 MeV. The adjustment leads always to a large value of the Coulomb reduced radius r_0 of around 1.21 – 1.24 fm.

The equations (6-7) have been obtained assuming, a priori, a specific expression for the Coulomb energy. Experimentally, the equivalent rms relative charge radius $R_0/A^{1/3}$ decreases with the mass [15,16] and has an isospin

Table 1

Coefficient values and root mean square deviation (in MeV) between the theoretical and experimental binding energies. The theoretical shell and pairing energies are taken into account. The Coulomb reduced radius $r_0 = R_0/A^{1/3}$ is fixed to 1.2257 fm in eq (6) while the Coulomb radius is determined by $R_0 = 1.28A^{1/3} - 0.76 + 0.8A^{-1/3}$ in eq. (7).

(Eq.)	a_v	k_v	a_s	k_s	a_k	k_k	r_0	f_p	k_1	k_2	k_3	σ
(1)	15.4099	1.7173	17.5528	1.4359	-	-	1.2179	1.3961	-	-	-	0.668
(2)	15.3579	1.8028	17.0362	1.9315	-	-	1.2311	1.0080	19.9524	-	-	0.621
(3)	15.4926	1.7899	18.2494	2.0205	-1.349	19.	1.2141	1.4603	-	-	-	0.662
(4)	15.2854	1.7450	17.0067	1.5948	-	-	1.2364	1.1924	-	0.5023	-	0.625
(5)	15.4817	1.8005	17.5771	1.7913	-	-	1.2245	0.9216	-	0.3199	-2.79	0.588
(6)	15.3838	1.7848	17.2149	1.8258	-	-	-	1.1241	15.936	-	-	0.625
(7)	15.6031	1.8503	18.1213	1.9934	-	-	-	1.8456	-	0.45	-2.5228	0.613

dependence and a mean value of 1.2257 fm. This value is imposed in the equation (6). The coefficients of the equation (7) have been obtained assuming that the Coulomb radius follows the expression $R_0 = 1.28A^{1/3} - 0.76 + 0.8A^{-1/3}$ proposed in Ref. [17]. It comes from the Droplet model and the proximity energy and simulates rather a central radius for which $R_0/A^{1/3}$ increases slightly with the mass. This radius is much smaller than the equivalent rms radius. This more elaborated expression can also be used to reproduce accurately the fusion, fission and cluster and alpha-decay data [18–21]. So it is possible to obtain accurate mass formulae with a large constant reduced radius r_0 or with a more sophisticated central radius corresponding to a smaller value of r_0 increasing with the mass.

The range of variation of the rms deviation over these different fits is not very large which indicates that comparisons of other predicted quantities such as fission barrier heights, energy of mirror nuclei, ..may help to discriminate between the new added terms. Let us recall also that the Duflo-Zuker fits [22] to the same set of masses have a rms deviation of around 370 keV.

A decrease of the radius coefficient r_0 and an increase of the surface coefficient a_s is observed when comparing the present adjustments on 2264 nuclear masses to the ones obtained previously on 2027 nuclei [7]. All the rms deviations between the theoretical and experimental masses are higher than the previous ones by around 0.04 – 0.05 MeV but the conclusion on the range of the main parameter values remains roughly identical : $a_v = 15.3 - 15.7$ MeV, $a_s = 16.8 - 18.3$ MeV, $k_v = 1.7 - 1.9$, $k_s = 1.4 - 2.8$, $r_0 = 1.21 - 1.24$ fm and $f_p = 0.9 - 2.0$. The correlations between the different terms of the LDM mass formulae have been deeply investigated in Ref. [11] using correlation and error matrix but starting directly from the four basic terms of the Bethe-Weizsäcker mass formula (see also [7]).

The difference (in absolute value) between the theoretical masses cal-

culated with the equations (1-5,7) and the experimental masses of the 2264 nuclei are given from the top left to the bottom right on the Figure 1. The structures observed are about the same for the different formulae. They come mainly from the assumed shell and pairing energies. The errors are much more important for the lighter nuclei. If only the nuclei verifying $A \geq 55$ are taken into account then the equation (5) becomes :

$$B = 15.3982 \left(1 - 1.7546I^2\right) A - 17.3401 \left(1 - 1.5981I^2\right) A^{\frac{2}{3}} - 0.6 \frac{e^2 Z^2}{1.2271 A^{\frac{1}{3}}} + 1.0867 \frac{Z^2}{A} - 0.356 |N - Z| \times e^{-(A/50)^2} + 1.359 \times e^{-80I^2} - E_{pair} - E_{shell}. \quad (2)$$

and the rms deviation is only 0.478 MeV for these 2010 nuclei. The Figure 2 displays the difference between the theoretical masses calculated with the above mentioned formula and the experimental masses of these 2010 nuclei.

As an illustration, the difference between the theoretical masses obtained with the equation (5) and the experimental masses of the 2264 nuclei is shown in Figure 3. The other formulae lead to similar figures.

The distribution and the number of the nuclei in each error range is given explicitly in Figure 4. The larger errors for the lighter nuclei come perhaps from the inadequacy of the shell effects to describe the cluster and halo formation.

4 Mass predictions for 976 exotic nuclei

Mass predictions from the equation (5) (not readjusted) are given in the Table 2 for 976 more exotic nuclei for which the mass is still unknown or known with an uncertainty higher or equal to 150 keV and lower than 800 keV. They are compared with the data given in the AME2012. The location of these 976 nuclei around the known valley of isotopes and the difference between the theoretical and empirical values are displayed in Figure 5. The rms deviation is 1.35 MeV. For about 45% of nuclei the difference is lower than 0.5 MeV and for 80% of nuclei the difference is lower than 1 MeV. These comparisons seem to confirm that this is the microscopic part of the mass formulae which induces these structures in ΔE . The distribution of the 976 nuclei in each error range is indicated in Figure 6.

When the coefficients of the equation (5) are readjusted on the whole 3240 masses the rms deviation reaches $\sigma = 0.769$ MeV, which justifies the adjustment on the 2264 best known nuclear masses.

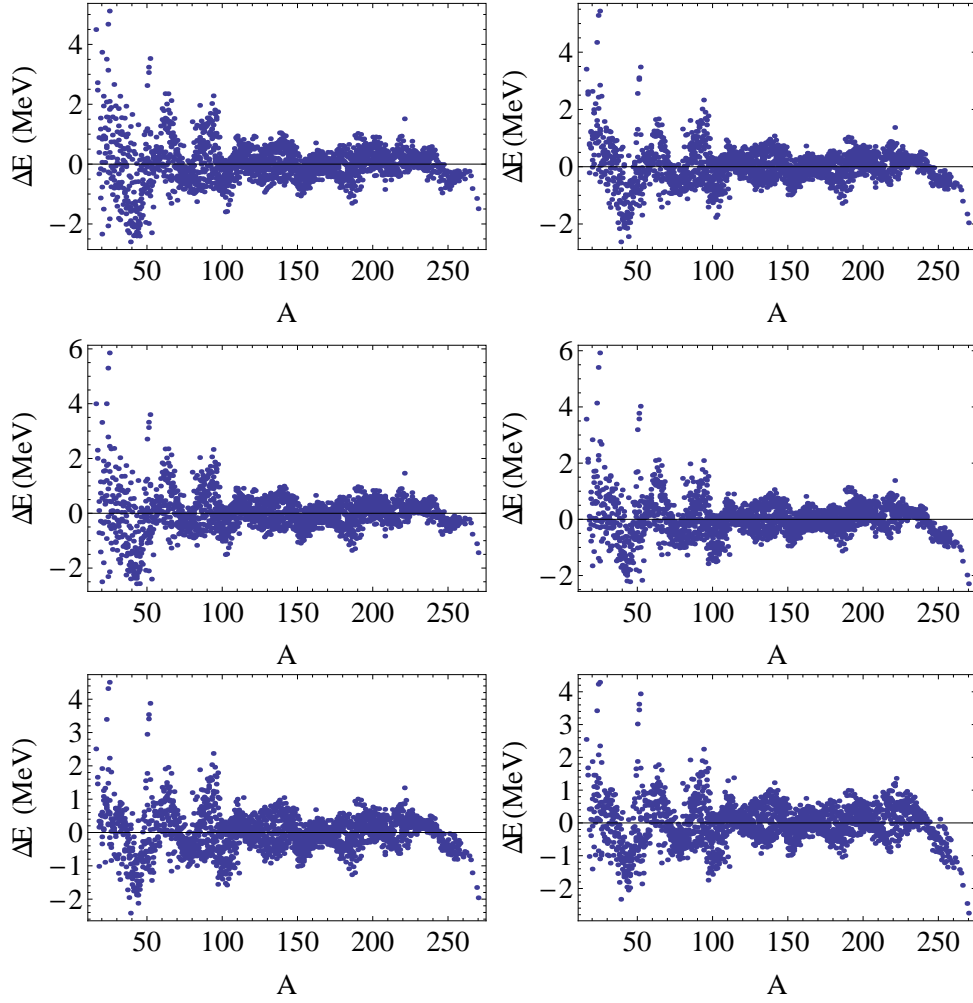


Fig. 1. Difference between the theoretical and experimental masses of the 2264 selected nuclei for the formulas (1-5) and (7) from the top left to the bottom right versus the mass number.

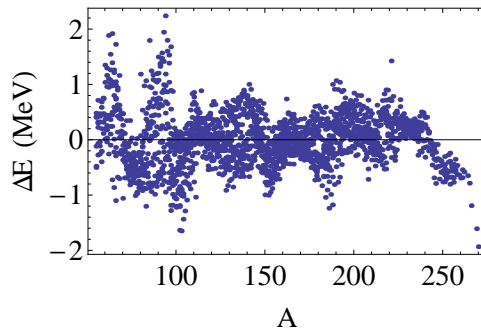


Fig. 2. Difference between the theoretical and experimental masses calculated from the formula (2) given in the text for the 2010 nuclei verifying $A \geq 55$.

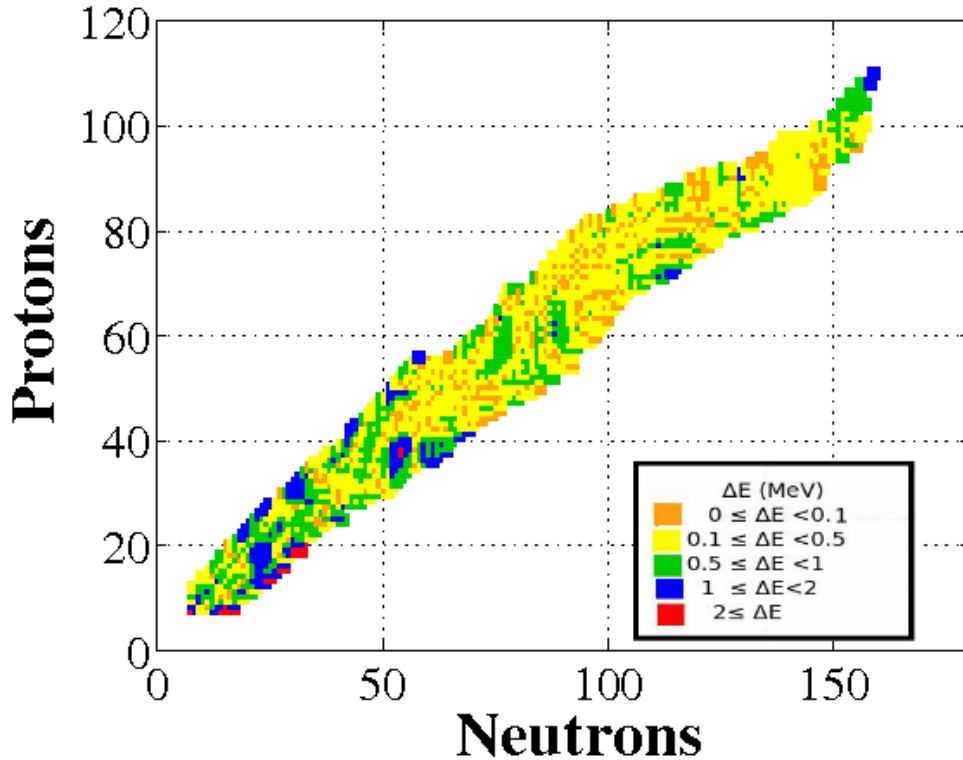


Fig. 3. Difference between the theoretical masses calculated from the equation (5) and the experimental masses of the 2264 selected nuclei.

5 Summary and conclusion

The coefficients of different macro-microscopic mass formulae including the pairing and shell energies of the Thomas-Fermi model have been determined by an adjustment to 2264 experimental atomic masses given in the recent AME2012 atomic mass evaluation. The usual Wigner term is more efficient than the curvature energy term to improve the accuracy of the formulae. The coefficients of these two terms are very unstable. Other exponential forms of the Wigner terms are more stable and efficient. A rms deviation of 0.59 MeV can be reached between the experimental and theoretical masses. The remaining differences come probably mainly from the determination of the shell and pairing energies. A large constant coefficient $r_0 = 1.22 - 1.23$ fm or a small central radius increasing with the mass can be used. The different fits lead rather to a low value of the surface energy coefficient of around 17-18 MeV. Predictions are advanced for masses of 976 selected more exotic nuclei.

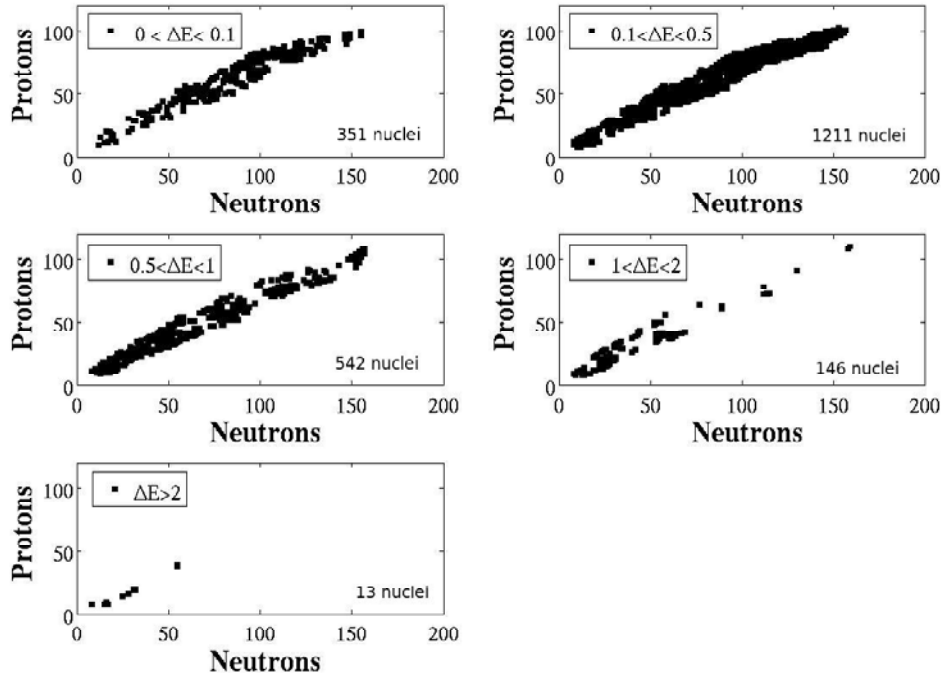


Fig. 4. Distribution of the 2264 nuclei in each error range.

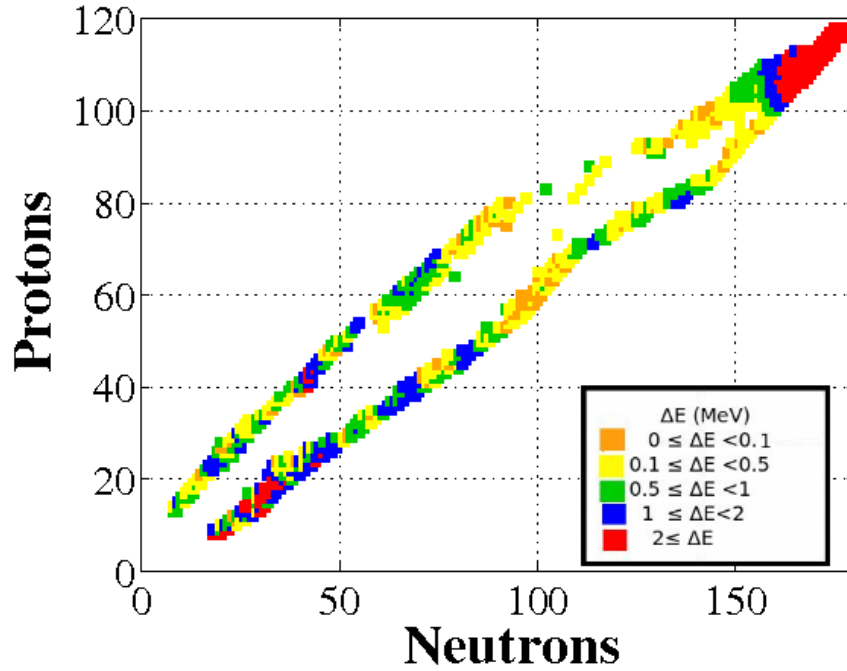


Fig. 5. Difference between the theoretical masses obtained from the equation (5) and 976 poorly known or extrapolated masses extracted from the AME2012 table.

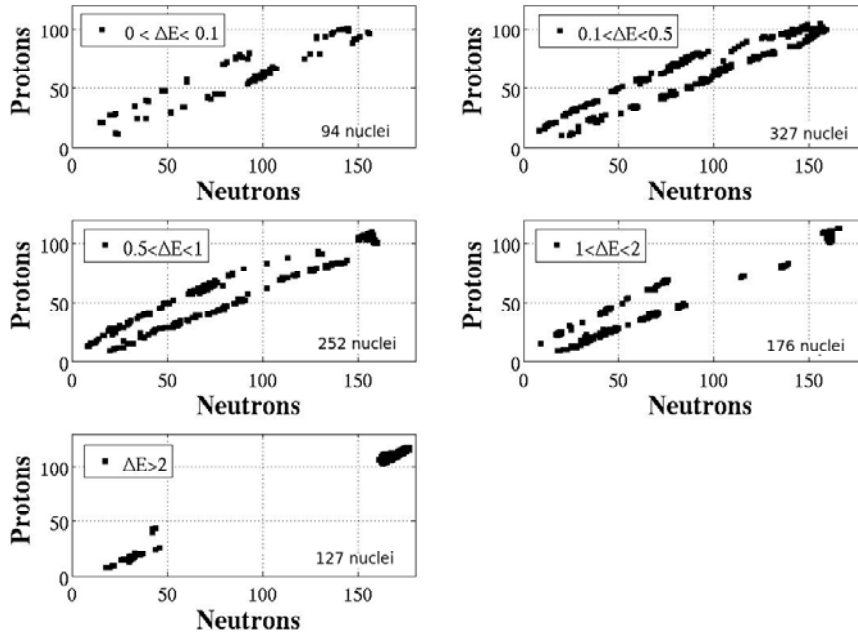


Fig. 6. Distribution of the 976 nuclei in each error range.

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Table 2

Theoretical mass excess (in MeV) predicted from the equation (5) and from the AME2012 table for 976 very exotic nuclei.

Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}
²¹ Al	26.99	27.65	²² Al	18.2	18.99	²² Si	33.34	33.62	²³ Si	23.7	24.33	²⁴ P	33.32	34.45
²⁵ P	19.74	20.54	²⁶ P	10.97	11.12	²⁶ O	34.73	37.89	²⁶ S	27.08	27.82	²⁷ O	44.45	48.05
²⁷ F	24.63	25.94	²⁷ S	17.03	17.92	²⁸ O	52.08	54.86	²⁸ F	32.92	34.11	²⁸ S	4.07	4.61
²⁸ Cl	27.52	27.87	²⁹ F	39.63	40.41	²⁹ Cl	13.77	14.14	³⁰ F	48.11	50.45	³⁰ Ne	23.04	22.68
³⁰ Cl	4.44	5.17	³⁰ Ar	21.49	21.02	³¹ F	55.62	57.92	³¹ Ne	30.82	32.24	³¹ Ar	11.29	11.67
³² Ne	37.	37.93	³² K	21.1	21.36	³³ Ne	46.	47.15	³³ Na	23.97	24.61	³³ K	7.04	7.72
³⁴ Ne	52.84	53.30	³⁴ Na	31.29	32.15	³⁴ K	-1.22	-1.08	³⁴ Ca	13.85	14.17	³⁵ Na	37.84	37.93
³⁵ Mg	15.64	15.71	³⁵ Ca	4.79	5.04	³⁶ Na	45.91	46.22	³⁶ Mg	20.38	19.85	³⁶ Sc	15.35	15.31
³⁷ Na	53.14	52.87	³⁷ Mg	28.29	27.80	³⁷ Sc	3.48	3.46	³⁸ Mg	34.07	32.90	³⁸ Al	16.21	14.86
³⁸ Sc	-4.55	-4.91	³⁸ Ti	10.67	9.99	³⁹ Mg	42.28	41.54	³⁹ Al	21.	19.62	³⁹ Ti	2.2	1.30
⁴⁰ Mg	48.61	47.14	⁴⁰ Al	27.97	26.79	⁴⁰ Si	5.43	3.16	⁴⁰ Ti	-8.85	-10.02	⁴⁰ V	11.89	10.33
⁴¹ Al	33.89	32.08	⁴¹ Si	12.12	10.01	⁴¹ V	0.2	-1.30	⁴² Al	40.84	41.15	⁴² Si	16.56	13.87
⁴² P	1.01	-1.32	⁴² V	-7.62	-9.46	⁴² Cr	6.24	4.78	⁴³ Al	47.94	50.57	⁴³ Si	23.1	22.64
⁴³ P	4.68	2.21	⁴³ Cr	-2.3	-3.67	⁴³ Si	28.51	30.12	⁴⁴ P	10.44	9.59	⁴⁴ Cl	-20.61	-21.45
⁴⁴ V	-24.12	-24.91	⁴⁴ Cr	-13.64	-14.99	⁴⁴ Mn	6.66	5.19	⁴⁵ Si	37.21	39.48	⁴⁵ P	15.32	18.02
⁴⁵ S	-3.99	-4.28	⁴⁵ Mn	-5.13	-6.42	⁴⁵ Fe	13.43	12.64	⁴⁶ P	22.78	25.76	⁴⁶ S	0.04	2.50
⁴⁶ Cl	-13.81	-13.97	⁴⁶ Mn	-12.96	-13.79	⁴⁶ Fe	0.59	-0.28	⁴⁷ P	29.24	30.15	⁴⁷ S	7.41	10.02
⁴⁷ Cl	-10.1	-7.88	⁴⁷ Fe	-7.59	-7.95	⁴⁷ Co	9.85	9.77	⁴⁸ S	12.76	14.88	⁴⁸ Cl	-4.06	-1.32
⁴⁸ Ar	-22.44	-20.47	⁴⁸ Mn	-29.32	-29.89	⁴⁸ Fe	-18.42	-18.90	⁴⁸ Co	0.87	0.82	⁴⁸ Ni	16.48	17.18
⁴⁹ S	21.2	23.15	⁴⁹ Cl	1.15	3.37	⁴⁹ Ar	-16.86	-14.16	⁴⁹ Co	-10.33	-10.41	⁴⁹ Ni	7.17	7.97
⁵⁰ Cl	8.43	10.66	⁵⁰ Ar	-12.92	-10.78	⁵⁰ Co	-17.78	-18.61	⁵⁰ Ni	-4.9	-4.51	⁵¹ Cl	14.48	16.10
⁵¹ Ar	-5.87	-3.79	⁵¹ Ni	-12.94	-13.00	⁵² Ar	-0.97	0.42	⁵² K	-16.54	-13.12	⁵² Co	-33.99	-35.02
⁵² Ni	-23.47	-24.11	⁵² Cu	-3.07	-3.20	⁵³ Ar	6.79	8.30	⁵³ K	-11.68	-8.89	⁵³ Ca	-28.46	-24.77
⁵³ Sc	-38.11	-36.13	⁵³ Cu	-14.35	-14.60	⁵⁴ K	-5.	-2.04	⁵⁴ Ca	-24.78	-21.86	⁵⁴ Sc	-33.6	-31.39
⁵⁴ Cu	-21.74	-22.80	⁵⁴ Zn	-7.42	-6.25	⁵⁴ K	0.71	3.19	⁵⁵ Ca	-18.35	-15.67	⁵⁵ Sc	-29.98	-28.58
⁵⁵ Ti	-41.67	-40.55	⁵⁵ Cu	-31.64	-32.52	⁵⁵ Zn	-14.92	-14.28	⁵⁶ K	7.93	9.63	⁵⁶ Ca	-13.9	-12.24
⁵⁶ Sc	-24.73	-23.29	⁵⁶ V	-46.12	-45.10	⁵⁶ Cu	-38.24	-39.17	⁵⁶ Zn	-25.58	-25.71	⁵⁶ Ga	-4.32	-4.04
⁵⁷ Ca	-6.87	-4.69	⁵⁷ Sc	-20.71	-19.92	⁵⁷ Ti	-33.87	-33.72	⁵⁷ V	-44.23	-43.84	⁵⁷ Zn	-32.55	-32.69
⁵⁷ Ga	-15.65	-15.48	⁵⁸ Ca	-1.92	-1.36	⁵⁸ Sc	-14.88	-14.08	⁵⁸ Ti	-31.11	-31.62	⁵⁸ Cr	-51.83	-51.89
⁵⁸ Ga	-23.49	-23.67	⁵⁸ Ge	-7.71	-8.10	⁵⁹ Sc	-10.3	-10.46	⁵⁹ Ti	-25.64	-26.01	⁵⁹ V	-37.83	-38.01
⁵⁹ Cr	-47.89	-48.14	⁵⁹ Ga	-33.97	-33.65	⁵⁹ Ge	-16.31	-16.43	⁶⁰ Sc	-4.05	-4.27	⁶⁰ Ti	-22.33	-23.49
⁶⁰ V	-33.24	-33.12	⁶⁰ Cr	-46.5	-47.43	⁶⁰ Ga	-39.78	-38.83	⁶⁰ Ge	-27.61	-27.29	⁶⁰ As	-5.7	-6.06
⁶¹ Sc	0.93	-0.43	⁶¹ Ti	-16.35	-17.54	⁶¹ V	-30.51	-30.76	⁶¹ Ge	-33.73	-33.15	⁶¹ As	-17.59	-17.18

Table 3
continued...

Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}
⁶² Ti	-12.57	-14.21	⁶² V	-25.48	-25.77	⁶² Mn	-48.48	-47.99	⁶² Ge	-41.9	-41.21	⁶² As	-24.58	-24.02
⁶³ Ti	-5.82	-7.03	⁶³ V	-21.99	-22.89	⁶³ Cr	-35.72	-35.66	⁶³ As	-33.63	-32.70	⁶⁴ V	-16.17	-16.47
⁶⁴ Cr	-33.46	-34.61	⁶⁴ As	-39.65	-38.24	⁶⁴ Se	-26.93	-26.69	⁶⁵ V	-11.64	-13.04	⁶⁵ Cr	-27.98	-28.40
⁶⁵ Se	-33.16	-32.60	⁶⁵ V	-5.61	-7.33	⁶⁶ Cr	-24.54	-25.98	⁶⁶ Se	-41.37	-41.11	⁶⁷ Cr	-18.48	-20.12
⁶⁷ Mn	-33.31	-34.20	⁶⁷ Fe	-46.07	-46.25	⁶⁷ Br	-32.93	-32.55	⁶⁸ Cr	-14.88	-16.93	⁶⁸ Mn	-28.3	-29.00
⁶⁸ Fe	-43.83	-45.11	⁶⁸ Br	-38.44	-38.40	⁶⁹ Mn	-24.54	-26.08	⁶⁹ Fe	-39.06	-39.99	⁶⁹ Co	-50.17	-51.21
⁶⁹ Kr	-32.44	-32.67	⁷⁰ Mn	-19.22	-20.60	⁷⁰ Fe	-36.31	-38.01	⁷⁰ Co	-46.92	-47.17	⁷⁰ Kr	-40.95	-41.50
⁷¹ Mn	-15.2	-17.05	⁷¹ Fe	-31.	-32.83	⁷¹ Co	-44.37	-45.31	⁷¹ Rb	-32.3	-32.66	⁷² Fe	-28.1	-30.27
⁷² Co	-39.78	-41.02	⁷² Rb	-38.12	-38.33	⁷³ Fe	-22.62	-24.41	⁷³ Co	-36.9	-38.62	⁷³ Rb	-46.08	-46.23
⁷³ Sr	-31.95	-32.55	⁷⁴ Fe	-19.24	-21.23	⁷⁴ Co	-32.46	-33.79	⁷⁴ Ni	-48.46	-49.36	⁷⁴ Sr	-40.83	-41.67
⁷⁵ Co	-29.1	-30.90	⁷⁵ Ni	-44.25	-44.97	⁷⁵ Sr	-46.62	-46.86	⁷⁶ Co	-24.1	-25.75	⁷⁶ Ni	-41.61	-42.94
⁷⁶ Y	-38.6	-39.24	⁷⁷ Ni	-36.75	-37.91	⁷⁷ Cu	-48.51	-49.56	⁷⁷ Y	-46.78	-47.26	⁷⁸ Ni	-34.13	-35.79
⁷⁸ Cu	-44.5	-45.38	⁷⁸ Y	-52.53	-52.41	⁷⁸ Zr	-41.3	-41.90	⁷⁹ Ni	-27.71	-28.18	⁷⁹ Cu	-41.9	-42.78
⁷⁹ Y	-58.36	-58.34	⁷⁹ Zr	-47.06	-47.04	⁸⁰ Cu	-36.43	-36.60	⁸⁰ Zr	-55.52	-54.39	⁸¹ Cu	-31.79	-31.88
⁸¹ Zr	-58.4	-57.86	⁸¹ Nb	-46.95	-46.42	⁸² Cu	-25.67	-24.98	⁸² Zn	-42.61	-42.63	⁸² Zr	-63.94	-61.81
⁸² Nb	-52.2	-51.32	⁸³ Zn	-36.74	-36.04	⁸³ Nb	-58.41	-56.75	⁸³ Mo	-46.69	-44.87	⁸⁴ Zn	-32.41	-31.91
⁸⁴ Ga	-44.28	-43.42	⁸⁴ Nb	-61.02	-59.33	⁸⁴ Mo	-54.5	-51.41	⁸⁵ Zn	-25.84	-24.93	⁸⁵ Ga	-40.06	-39.41
⁸⁵ Tc	-46.03	-43.77	⁸⁶ Ga	-34.46	-33.15	⁸⁶ Ge	-49.76	-49.23	⁸⁶ Tc	-51.3	-49.30	⁸⁷ Ga	-29.58	-28.66
⁸⁷ Ge	-44.08	-43.18	⁸⁷ Ru	-45.93	-43.98	⁸⁸ Ge	-40.14	-39.45	⁸⁸ As	-50.72	49.81	⁸⁸ Ru	-54.4	-52.37
⁸⁹ Ge	-33.73	-32.96	⁸⁹ As	-46.8	-46.26	⁸⁹ Ru	-58.11	-56.97	⁸⁹ Rh	-46.03	-44.88	⁹⁰ Ge	-29.22	-28.76
⁹⁰ As	-41.33	-40.60	⁹⁰ Se	-55.8	-55.38	⁹⁰ Rh	-51.96	-50.69	⁹¹ As	-36.9	-36.61	⁹¹ Se	-50.34	-49.82
⁹¹ Rh	-58.8	-58.00	⁹¹ Pd	-46.28	-45.05	⁹² As	-30.98	-30.49	⁹² Se	-46.72	-46.69	⁹² Pd	-55.07	-53.63
⁹³ Se	-40.72	-40.75	⁹³ Br	-52.97	-52.75	⁹³ Pd	-59.14	-58.55	⁹³ Ag	-46.27	-46.13	⁹⁴ Se	-36.8	-37.25
⁹⁴ Br	-47.6	-47.92	⁹⁴ Ag	-52.41	-52.26	⁹⁵ Se	-30.46	-31.19	⁹⁵ Br	-43.77	-44.55	⁹⁵ Ag	-59.6	-59.81
⁹⁵ Cd	-46.63	-46.55	⁹⁶ Br	-38.16	-39.29	⁹⁶ Cd	-55.57	-55.45	⁹⁷ Br	-34.06	-35.43	⁹⁷ Cd	-60.45	-60.38
⁹⁷ In	-47.19	-48.09	⁹⁸ Br	-28.45	-29.48	⁹⁸ Kr	-44.31	-45.85	⁹⁸ In	-53.9	-54.33	⁹⁹ Kr	-38.76	-40.06
⁹⁹ In	-61.38	-62.03	⁹⁹ Sn	-47.94	-48.59	¹⁰⁰ Kr	-35.05	-36.39	¹⁰⁰ Rb	-46.55	-47.47	¹⁰⁰ In	-64.31	-65.02
¹⁰⁰ Sn	-57.28	-57.45	¹⁰¹ Kr	-29.13	-30.32	¹⁰¹ Rb	-42.81	-43.90	¹⁰¹ In	-68.61	-69.75	¹⁰¹ Sn	-60.31	-60.84
¹⁰² Rb	-37.71	-38.57	¹⁰³ Rb	-33.61	-34.75	¹⁰³ Sr	-47.42	-48.30	¹⁰³ Sb	-56.18	-56.33	¹⁰⁴ Sr	-44.11	-45.18
¹⁰⁴ Y	-54.06	-54.73	¹⁰⁵ Sr	-38.61	-39.70	¹⁰⁵ Y	-50.82	-51.69	¹⁰⁵ Te	-52.81	-52.08	¹⁰⁶ Sr	-34.79	-36.32
¹⁰⁶ Y	-46.05	-46.91	¹⁰⁶ Zr	-58.91	-60.02	¹⁰⁷ Sr	-28.9	-30.37	¹⁰⁷ Y	-42.36	-43.60	¹⁰⁷ Zr	-54.27	-55.38
¹⁰⁷ I	-49.57	-48.32	¹⁰⁸ Y	-37.3	-38.39	¹⁰⁸ Zr	-51.35	-52.73	¹⁰⁹ Y	-33.2	-34.36	¹⁰⁹ Zr	-46.19	-47.67
¹⁰⁹ Nb	-56.62	-58.06	¹⁰⁹ Xe	-46.17	-44.82	¹¹⁰ Zr	-42.89	-44.25	¹¹⁰ Nb	-52.14	-53.68	¹¹¹ Zr	-37.56	-38.43

Table 4
continued...

Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}
¹¹¹ Nb	-48.88	-50.42	¹¹² Zr	-33.81	-34.35	¹¹² Nb	-44.27	-45.29	¹¹² Mo	-57.46	-58.56	¹¹³ Nb	-40.51	-40.79
¹¹³ Mo	-52.77	-52.87	¹¹⁴ Nb	-35.39	-35.38	¹¹⁴ Mo	-49.81	-50.15	¹¹⁴ Tc	-58.77	-58.68	¹¹⁴ I	-72.8	-72.91
¹¹⁵ Nb	-31.35	-31.66	¹¹⁵ Mo	-44.75	-45.14	¹¹⁵ Tc	-55.91	-56.05	¹¹⁵ Cs	-59.7	-59.78	¹¹⁵ Ba	-49.03	-48.59
¹¹⁶ Mo	-41.5	-42.09	¹¹⁶ Tc	-51.46	-51.66	¹¹⁶ Cs	-62.06	-62.52	¹¹⁶ Ba	-54.7	-54.58	¹¹⁶ La	-40.7	-40.46
¹¹⁷ Mo	-36.17	-36.90	¹¹⁷ Tc	-48.38	-48.67	¹¹⁷ Ru	-59.52	-59.80	¹¹⁷ Ba	-57.62	-57.50	¹¹⁷ La	-46.59	-46.66
¹¹⁸ Tc	-43.79	-44.17	¹¹⁸ Ru	-57.26	-57.51	¹¹⁸ Ba	-62.35	-62.46	¹¹⁸ La	-49.62	-50.28	¹¹⁹ Tc	-40.37	-40.88
¹¹⁹ Ru	-52.56	-53.05	¹¹⁹ Ba	-64.59	-64.70	¹¹⁹ La	-54.97	-55.40	¹¹⁹ Ce	-44.05	-44.32	¹²⁰ Tc	-35.52	-36.10
¹²⁰ Ru	-50.01	-50.43	¹²⁰ Rh	-58.82	-58.90	¹²⁰ Ba	-68.89	-69.01	¹²⁰ La	-57.69	-58.21	¹²⁰ Ce	-49.8	-50.17
¹²¹ Ru	-45.05	-45.82	¹²¹ Rh	-56.43	-56.45	¹²¹ La	-62.27	-62.63	¹²¹ Ce	-52.77	-53.18	¹²¹ Pr	-41.62	-42.21
¹²² Ru	-42.41	-42.81	¹²² Rh	-52.17	-52.43	¹²² La	-64.54	-65.00	¹²² Ce	-57.87	-58.26	¹²² Pr	-44.95	-45.89
¹²³ Ru	-37.36	-37.81	¹²³ Rh	-49.51	-49.59	¹²³ Pd	-60.42	-60.52	¹²³ La	-68.65	-68.95	¹²³ Ce	-60.29	-60.72
¹²³ Pr	-50.34	-51.04	¹²⁴ Ru	-34.42	-35.09	¹²⁴ Rh	-45.17	-45.18	¹²⁴ Pd	-58.55	-58.66	¹²⁴ Ag	-66.2	-66.05
¹²⁴ Ce	-64.92	-65.24	¹²⁴ Pr	-53.15	-54.11	¹²⁴ Nd	-44.53	-45.41	¹²⁵ Rh	-42.21	-42.56	¹²⁵ Pd	-54.22	-54.72
¹²⁵ Ag	-64.23	-64.58	¹²⁵ Ce	-66.66	-67.18	¹²⁵ Pr	-58.03	-58.70	¹²⁵ Nd	-47.6	-48.55	¹²⁶ Rh	-37.76	-38.88
¹²⁶ Pd	-52.02	-52.86	¹²⁶ Ag	-60.78	-61.14	¹²⁶ Pr	-60.32	-61.22	¹²⁶ Nd	-52.99	-53.78	¹²⁶ Pm	-39.2	-40.57
¹²⁷ Pd	-47.44	-48.88	¹²⁷ Ag	-58.58	-59.24	¹²⁷ Pr	-64.54	-65.24	¹²⁷ Nd	-55.54	-56.40	¹²⁷ Pm	-44.79	-45.89
¹²⁸ Pd	-44.87	-46.19	¹²⁸ Ag	-54.9	-55.83	¹²⁸ Nd	-60.31	-61.02	¹²⁸ Pm	-47.79	-49.12	¹²⁸ Sm	-38.73	-39.50
¹²⁹ Ag	-52.21	-53.27	¹²⁹ Cd	-63.51	-64.63	¹²⁹ Nd	-62.32	-63.08	¹²⁹ Pm	-52.88	-53.85	¹²⁹ Sm	-42.14	-42.82
¹³⁰ Ag	-45.92	-47.13	¹³⁰ Cd	-61.53	-62.66	¹³⁰ Pm	-55.4	-56.53	¹³⁰ Sm	-47.51	-48.24	¹³⁰ Eu	-33.82	-34.24
¹³¹ Cd	-55.33	-56.56	¹³¹ Pm	-59.92	-60.56	¹³¹ Sm	-50.13	-50.99	¹³¹ Eu	-39.27	-39.86	¹³² Cd	-50.26	-52.09
¹³² Pm	-61.63	-62.61	¹³² Sm	-55.08	-55.80	¹³² Eu	-42.23	-43.31	¹³³ Cd	-43.92	-45.28	¹³³ In	-57.46	-58.53
¹³³ Sm	-57.23	-57.85	¹³³ Eu	-47.24	-48.22	¹³³ Gd	-36.02	-36.76	¹³⁴ In	-51.66	-52.17	¹³⁴ Sm	-61.38	-61.81
¹³⁴ Eu	-49.93	-50.87	¹³⁴ Gd	-41.3	-42.33	¹³⁵ In	-46.53	-47.29	¹³⁵ Eu	-54.15	-54.95	¹³⁵ Gd	-44.29	-45.11
¹³⁵ Tb	-32.83	-33.81	¹³⁶ Sn	-55.9	-56.13	¹³⁶ Eu	-56.24	-56.94	¹³⁶ Gd	-49.09	-49.79	¹³⁶ Tb	-36.06	-37.22
¹³⁷ Sn	-49.79	-49.62	¹³⁷ Sb	-60.03	-60.23	¹³⁷ Eu	-60.12	-60.41	¹³⁷ Gd	-51.21	-51.90	¹³⁷ Tb	-40.97	-41.94
¹³⁸ Sn	-44.86	-45.04	¹³⁸ Sb	-54.54	-53.58	¹³⁸ Gd	-55.66	-56.18	¹³⁸ Tb	-43.67	-44.64	¹³⁸ Dy	-34.93	-35.86
¹³⁹ Sb	-49.79	-49.30	¹³⁹ Gd	-57.63	-57.85	¹³⁹ Tb	-48.13	-48.82	¹³⁹ Dy	-37.64	-38.74	¹⁴⁰ Sb	-43.94	-43.10
¹⁴⁰ I	-63.6	-62.76	¹⁴⁰ Tb	-50.48	-51.31	¹⁴⁰ Dy	-42.83	-43.60	¹⁴⁰ Ho	-29.26	-30.57	¹⁴¹ Te	-50.49	-49.57
¹⁴¹ I	-59.9	-59.26	¹⁴¹ Dy	-45.38	-45.99	¹⁴¹ Ho	-34.36	-35.37	¹⁴² Te	-46.37	-45.76	¹⁴² I	-54.77	-53.88
¹⁴² Tb	-56.56	-56.09	¹⁴² Dy	-50.12	-50.43	¹⁴² Ho	-37.25	-38.54	¹⁴² Er	-27.85	-28.89	¹⁴³ Te	-40.28	-39.73
¹⁴³ Eu	-50.63	-50.25	¹⁴³ Gd	-68.23	-67.70	¹⁴³ Ho	-42.05	-42.97	¹⁴³ Er	-31.09	-32.01	¹⁴⁴ I	-45.28	-44.80
¹⁴⁴ Er	-36.61	-37.01	¹⁴⁴ Tm	-22.09	-23.58	¹⁴⁵ I	-40.94	-40.93	¹⁴⁵ Er	-39.08	-38.61	¹⁴⁵ Tm	-27.58	-28.65
¹⁴⁶ Tm	-30.89	-30.67	¹⁴⁷ Xe	-42.61	-42.79	¹⁴⁸ Xe	-39.	-39.14	¹⁴⁸ Cs	-47.3	-47.28	¹⁴⁸ Yb	-30.2	-29.96

Table 5
continued...

Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}
¹⁴⁹ Cs	-43.76	-43.66	¹⁴⁹ Ba	-53.02	-53.33	¹⁴⁹ La	-60.22	-60.76	¹⁴⁹ Tm	-43.88	-44.09	¹⁴⁹ Yb	-33.2	-33.26
¹⁵⁰ Cs	-38.82	-38.58	¹⁵⁰ Ba	-50.25	-50.33	¹⁵⁰ La	-56.38	-56.83	¹⁵⁰ Tm	-46.49	-46.67	¹⁵⁰ Yb	-38.64	-38.67
¹⁵⁰ Lu	-24.64	-24.91	¹⁵¹ Cs	-34.86	-34.68	¹⁵¹ Ba	-45.39	-45.40	¹⁵¹ La	-53.73	-53.93	¹⁵¹ Yb	-41.54	-41.32
¹⁵¹ Lu	-30.11	-30.35	¹⁵² Ba	-42.09	-42.01	¹⁵² La	-49.54	-49.54	¹⁵² Ce	-59.06	-59.40	¹⁵² Yb	-46.32	-46.58
¹⁵² Lu	-33.42	-33.55	¹⁵³ Ba	-36.92	-36.81	¹⁵³ La	-46.24	-46.26	¹⁵³ Ce	-55.02	-55.14	¹⁵³ Yb	-47.21	-47.31
¹⁵³ Lu	-38.42	-38.86	¹⁵³ Hf	-27.3	-27.24	¹⁵⁴ La	-41.76	-41.59	¹⁵⁴ Ce	-52.35	-52.45	¹⁵⁴ Lu	-39.72	-40.16
¹⁵⁴ Hf	-32.73	-33.24	¹⁵⁵ La	-38.18	-38.03	¹⁵⁵ Ce	-47.93	-47.89	¹⁵⁵ Hf	-34.36	-34.51	¹⁵⁵ Ta	-23.99	-24.81
¹⁵⁶ Ce	-44.87	-44.88	¹⁵⁶ Pr	-51.57	-51.48	¹⁵⁶ Nd	-60.47	-60.47	¹⁵⁶ Hf	-37.87	-37.97	¹⁵⁶ Ta	-26.05	-26.59
¹⁵⁷ Ce	-40.01	-39.99	¹⁵⁷ Pr	-48.54	-48.53	¹⁵⁷ Hf	-38.9	-38.79	¹⁵⁷ Ta	-29.64	-30.18	¹⁵⁷ W	-19.71	-20.07
¹⁵⁸ Pr	-44.33	-44.13	¹⁵⁸ Nd	-54.06	-54.13	¹⁵⁸ Ta	-31.17	-31.40	¹⁵⁸ W	-23.7	-24.21	¹⁵⁹ Pr	-41.09	-40.99
¹⁵⁹ Nd	-49.81	-49.83	¹⁵⁹ W	-25.49	-25.35	¹⁵⁹ Re	-14.74	-15.58	¹⁶⁰ Nd	-47.13	-47.18	¹⁶⁰ Pm	-53.	-52.92
¹⁶⁰ W	-29.38	-28.97	¹⁶⁰ Re	-16.93	-17.36	¹⁶¹ Nd	-42.59	-42.67	¹⁶¹ Pm	-50.24	-50.34	¹⁶¹ W	-30.56	-30.35
¹⁶¹ Re	-20.89	-20.93	¹⁶¹ Os	-10.22	-10.54	¹⁶² Pm	-46.37	-46.33	¹⁶² Sm	-54.53	-54.98	¹⁶² Re	-22.5	-22.86
¹⁶² Os	-14.5	-14.55	¹⁶³ Pm	-43.25	-43.37	¹⁶³ Sm	-50.72	-51.05	¹⁶³ Os	-16.39	-16.27	¹⁶⁴ Sm	-48.1	-48.61
¹⁶⁴ Eu	-53.33	-53.20	¹⁶⁴ Gd	-59.77	-59.87	¹⁶⁴ Os	-20.47	-20.11	¹⁶⁴ Ir	-7.54	-7.98	¹⁶⁵ Sm	-43.81	-44.12
¹⁶⁵ Eu	-50.69	-50.87	¹⁶⁵ Gd	-56.49	-56.54	¹⁶⁵ Tb	-60.57	-60.34	¹⁶⁵ Os	-21.8	-21.71	¹⁶⁵ Ir	-11.64	-11.70
¹⁶⁶ Eu	-46.93	-46.93	¹⁶⁶ Gd	-54.53	-54.69	¹⁶⁶ Ir	-13.35	-13.66	¹⁶⁶ Pt	-4.79	-4.78	¹⁶⁷ Eu	-43.88	-43.94
¹⁶⁷ Gd	-50.81	-50.87	¹⁶⁷ Tb	-55.93	-55.82	¹⁶⁷ Re	-34.84	-34.88	¹⁶⁷ Pt	-6.81	-6.56	¹⁶⁸ Gd	-48.36	-48.41
¹⁶⁸ Tb	-52.72	-52.51	¹⁶⁸ Pt	-11.06	-10.43	¹⁶⁹ Gd	-44.15	-43.99	¹⁶⁹ Tb	-50.33	-50.18	¹⁶⁹ Dy	-55.6	-55.46
¹⁶⁹ Pt	-12.51	-12.32	¹⁶⁹ Au	-1.79	-2.11	¹⁷⁰ Tb	-46.72	-46.36	¹⁷⁰ Dy	-53.66	-53.64	¹⁷⁰ Ir	-23.36	-23.57
¹⁷⁰ Au	-3.75	-4.05	¹⁷¹ Tb	-44.03	-43.74	¹⁷¹ Dy	-50.19	-49.95	¹⁷¹ Ho	-54.52	-54.36	¹⁷¹ Hg	3.29	3.17
¹⁷² Dy	-48.01	-47.87	¹⁷² Ho	-51.48	-51.23	¹⁷² Hg	-1.11	-0.89	¹⁷³ Dy	-43.94	-43.87	¹⁷³ Ho	-49.35	-49.29
¹⁷³ Er	-53.65	-53.64	¹⁷³ Hg	-2.71	-2.61	¹⁷⁴ Ho	-45.69	-45.86	¹⁷⁴ Er	-51.95	-52.22	¹⁷⁴ Au	-14.24	-14.05
¹⁷⁵ Ho	-43.2	-43.49	¹⁷⁵ Er	-48.65	-48.90	¹⁷⁶ Er	-46.63	-47.08	¹⁷⁷ Er	-42.86	-43.29	¹⁷⁷ Tm	-47.47	-47.92
¹⁷⁸ Tm	-44.12	-44.63	¹⁷⁸ Ta	-50.6	-50.88	¹⁷⁸ Tl	-4.79	-4.56	¹⁷⁹ Tm	-41.6	-42.41	¹⁷⁹ Yb	-46.54	-47.02
¹⁸⁰ Yb	-44.6	-45.32	¹⁸¹ Yb	-41.09	-41.79	¹⁸¹ Lu	-44.8	-45.41	¹⁸² Lu	-41.88	-42.40	¹⁸⁴ Lu	-36.41	-37.23
¹⁸⁵ Lu	-33.89	-34.91	¹⁸⁵ Bi	-2.24	-1.54	¹⁸⁷ Hf	-32.82	-34.15	¹⁸⁸ Hf	-30.88	-32.02	¹⁸⁹ Hf	-27.16	-28.02
¹⁸⁹ Ta	-31.83	-32.78	¹⁹⁰ Ta	-28.51	-29.27	¹⁹⁰ Tl	-24.38	-24.49	¹⁹¹ Ta	-26.49	-27.21	¹⁹² Ta	-23.16	-22.89
¹⁹² W	-29.65	-30.24	¹⁹³ W	-26.29	-25.93	¹⁹⁴ W	-24.53	-24.32	¹⁹⁴ Re	-27.24	-27.38	¹⁹⁴ Bi	-16.04	-15.93
¹⁹⁵ Re	-25.58	-25.20	¹⁹⁶ Re	-22.54	-22.12	¹⁹⁷ Re	-20.5	-20.45	¹⁹⁷ Os	-25.31	-24.90	¹⁹⁸ Re	-17.14	-17.32
¹⁹⁸ Os	-23.84	-23.71	¹⁹⁸ Ir	-25.82	-25.59	¹⁹⁸ At	-6.72	-6.26	¹⁹⁹ Os	-20.48	-20.67	²⁰⁰ Os	-18.78	-19.11
²⁰⁰ Ir	-21.61	-21.72	²⁰¹ Os	-15.24	-15.96	²⁰¹ Ir	-19.9	-20.22	²⁰¹ Ra	11.84	12.43	²⁰² Os	-13.09	-13.73
²⁰² Ir	-16.78	-17.46	²⁰² Fr	3.09	3.48	²⁰³ Ir	-14.69	-15.28	²⁰³ Pt	-19.63	-20.21	²⁰⁴ Ir	-9.69	-10.29

Table 6
continued...

Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}
²⁰⁴ Pt	-17.92	-18.41	²⁰⁴ Au	-20.65	-20.72	²⁰⁵ Pt	-12.97	-13.58	²⁰⁵ Au	-18.77	-19.06	²⁰⁶ Pt	-9.63	-10.31
²⁰⁶ Au	-14.22	-14.50	²⁰⁶ Ac	13.46	13.79	²⁰⁷ Au	-10.81	-11.37	²⁰⁸ Au	-6.1	-6.30	²⁰⁹ Au	-2.47	-2.52
²⁰⁹ Hg	-8.64	-8.87	²¹⁰ Au	2.33	2.76	²¹⁰ Hg	-5.37	-5.51	²¹¹ Hg	-0.62	-0.28	²¹² Hg	2.76	3.17
²¹² Tl	-1.55	-1.19	²¹³ Hg	7.67	8.53	²¹⁴ Hg	11.18	12.03	²¹⁴ Tl	6.47	7.21	²¹⁵ Hg	16.21	17.64
²¹⁵ Tl	9.91	10.78	²¹⁵ Pb	4.42	5.31	²¹⁶ Hg	19.86	21.34	²¹⁶ Tl	14.72	15.96	²¹⁶ Pb	7.48	8.32
²¹⁷ Tl	18.31	19.56	²¹⁷ Pb	12.24	13.23	²¹⁷ U	22.97	22.66	²¹⁸ Tl	23.09	24.44	²¹⁸ Pb	15.45	16.42
²¹⁹ Pb	20.28	21.53	²¹⁹ Bi	16.28	17.11	²¹⁹ Np	29.28	28.80	²²⁰ Pb	23.67	24.91	²²⁰ Bi	20.82	21.73
²²⁰ Pa	20.22	21.02	²²⁰ U	22.93	22.90	²²⁰ Np	30.31	30.19	²²¹ Bi	24.1	24.97	²²¹ U	24.48	24.35
²²¹ Np	29.85	29.92	²²¹ Bi	28.67	29.77	²²² Pa	22.16	21.51	²²² U	24.22	24.46	²²² Np	31.02	31.90
²²³ Bi	32.14	33.04	²²³ Po	27.08	27.85	²²³ Np	30.6	30.18	²²⁴ Bi	36.77	37.57	²²⁴ Po	29.91	30.73
²²⁴ Np	31.88	31.44	²²⁵ Po	34.53	35.17	²²⁵ At	30.4	30.73	²²⁶ Po	37.55	38.25	²²⁶ At	34.61	34.76
²²⁶ Np	32.78	32.73	²²⁷ Po	42.28	42.89	²²⁷ At	37.48	37.76	²²⁸ At	41.68	42.01	²²⁹ At	44.82	45.07
²³⁰ Rn	42.05	42.59	²³⁰ Am	42.93	42.80	²³¹ Rn	46.45	46.86	²³¹ Am	42.44	42.43	²³² Fr	45.99	46.43
²³² Np	37.36	37.60	²³² Am	43.27	43.49	²³² Cm	46.4	46.51	²³³ Fr	49.03	49.33	²³³ Am	43.26	43.42
²³⁴ Am	44.46	44.72	²³⁴ Bk	53.34	53.39	²³⁵ Ra	51.2	51.26	²³⁵ Cm	48.01	48.32	²³⁵ Bk	52.7	52.84
²³⁶ Am	46.04	46.50	²³⁶ Bk	53.54	53.72	²³⁷ Ac	54.28	54.06	²³⁷ Am	46.57	47.01	²³⁷ Bk	53.19	53.42
²³⁸ Th	52.63	52.45	²³⁸ Bk	54.22	54.63	²³⁸ Cf	57.28	57.48	²³⁹ Th	56.61	56.38	²³⁹ Pa	53.34	53.30
²³⁹ Bk	54.25	54.62	²³⁹ Cf	58.25	58.66	²³⁹ Es	63.56	63.57	²⁴⁰ Pa	56.8	56.88	²⁴⁰ Bk	55.67	55.98
²⁴⁰ Es	64.2	64.36	²⁴¹ Pa	59.69	59.52	²⁴¹ U	56.2	56.19	²⁴¹ Bk	56.03	56.42	²⁴¹ Cf	59.33	59.54
²⁴¹ Es	63.86	63.84	²⁴¹ Fm	69.13	69.26	²⁴² U	58.62	58.45	²⁴² Np	57.42	57.52	²⁴² Bk	57.74	58.18
²⁴² Es	64.8	64.88	²⁴² Fm	68.4	68.38	²⁴³ U	62.4	62.26	²⁴³ Np	59.88	59.73	²⁴³ Cf	60.99	61.05
²⁴³ Es	64.75	64.85	²⁴³ Fm	69.36	69.36	²⁴⁴ Np	63.2	63.20	²⁴⁴ Es	66.03	65.93	²⁴⁴ Fm	68.97	68.92
²⁴⁵ Np	65.95	65.50	²⁴⁵ Es	66.37	66.19	²⁴⁵ Fm	70.19	69.94	²⁴⁵ Md	75.27	75.30	²⁴⁶ Am	64.99	64.56
²⁴⁶ Es	67.9	67.74	²⁴⁶ Md	76.12	76.22	²⁴⁷ Pu	69.11	68.80	²⁴⁷ Am	67.15	66.69	²⁴⁷ Fm	71.67	71.31
²⁴⁷ Md	75.94	75.77	²⁴⁸ Am	70.56	70.21	²⁴⁸ Bk	68.08	67.83	²⁴⁸ Es	70.3	70.08	²⁴⁸ Md	77.15	76.85
²⁴⁸ No	80.62	80.36	²⁴⁹ Am	73.1	72.30	²⁴⁹ Es	71.18	70.88	²⁴⁹ Md	77.23	76.92	²⁴⁹ No	81.78	81.43
²⁵⁰ Es	73.23	72.80	²⁵⁰ Md	78.63	78.27	²⁵⁰ No	81.56	81.10	²⁵¹ No	82.85	82.40	²⁵¹ Lr	87.73	87.33
²⁵² Cm	79.06	79.03	²⁵² Bk	78.54	78.47	²⁵² Md	80.51	80.05	²⁵² Lr	88.74	88.28	²⁵³ Bk	80.93	80.79
²⁵³ Md	81.18	80.77	²⁵³ Lr	88.58	88.02	²⁵³ Rf	93.56	93.22	²⁵⁴ Bk	84.39	84.52	²⁵⁴ Md	83.45	83.21
²⁵⁴ Lr	89.87	89.21	²⁵⁴ Rf	93.2	92.59	²⁵⁵ Cf	84.81	84.69	²⁵⁵ Rf	94.33	93.61	²⁵⁵ Db	99.73	99.13
²⁵⁶ Cf	87.04	86.94	²⁵⁶ Es	87.19	86.99	²⁵⁶ Md	87.46	87.03	²⁵⁶ Db	100.5	99.79	²⁵⁷ Es	89.4	89.07
²⁵⁷ Lr	92.61	92.08	²⁵⁷ Db	100.21	99.57	²⁵⁸ Es	92.7	92.42	²⁵⁸ Fm	90.43	89.95	²⁵⁸ No	91.48	91.82
²⁵⁸ Lr	94.78	94.24	²⁵⁸ Db	101.8	101.08	²⁵⁸ Sg	105.24	104.52	²⁵⁹ Fm	93.71	93.08	²⁵⁹ Md	93.63	93.03

Table 7
continued...

Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}	Nucleus	E_{th}	E_{AME}
²⁵⁹ No	94.11	93.67	²⁵⁹ Lr	95.85	95.47	²⁵⁹ Rf	98.36	97.85	²⁵⁹ Sg	106.56	105.86	²⁶⁰ Fm	95.77	94.93
²⁶⁰ Md	96.55	95.78	²⁶⁰ No	95.61	94.88	²⁶⁰ Lr	98.28	97.66	²⁶⁰ Rf	99.15	98.64	²⁶⁰ Db	103.67	103.05
²⁶⁰ Bh	113.32	112.53	²⁶¹ Md	98.58	97.60	²⁶¹ No	98.46	97.66	²⁶¹ Lr	99.56	98.79	²⁶¹ Db	104.25	103.76
²⁶¹ Bh	113.14	112.38	²⁶² Md	101.63	100.53	²⁶² No	100.1	98.94	²⁶² Lr	102.1	101.19	²⁶² Rf	102.39	101.49
²⁶² Db	106.26	105.51	²⁶² Bh	114.54	113.61	²⁶³ No	103.13	101.81	²⁶³ Lr	103.73	102.40	²⁶³ Rf	104.79	103.71
²⁶³ Db	107.11	106.19	²⁶³ Sg	110.19	109.50	²⁶³ Bh	114.5	113.76	²⁶³ Hs	119.72	119.05	²⁶⁴ No	105.01	103.34
²⁶⁴ Lr	106.38	104.93	²⁶⁴ Rf	106.08	104.64	²⁶⁴ Db	109.36	108.03	²⁶⁴ Sg	110.78	109.80	²⁶⁴ Bh	116.06	115.16
²⁶⁵ Lr	108.23	106.40	²⁶⁵ Rf	108.69	107.08	²⁶⁵ Db	110.49	108.8	²⁶⁵ Sg	112.8	111.57	²⁶⁵ Bh	116.36	115.38
²⁶⁵ Mt	126.68	126.00	²⁶⁶ Lr	111.62	109.34	²⁶⁶ Rf	110.08	108.1	²⁶⁶ Db	112.74	110.99	²⁶⁶ Sg	113.62	111.96
²⁶⁶ Bh	118.11	116.78	²⁶⁶ Mt	127.96	126.87	²⁶⁷ Rf	113.45	111.07	²⁶⁷ Db	114.08	111.92	²⁶⁷ Sg	115.84	114.01
²⁶⁷ Bh	118.77	117.12	²⁶⁷ Hs	122.65	121.31	²⁶⁷ Mt	127.79	126.73	²⁶⁷ Ds	133.92	132.95	²⁶⁸ Rf	115.48	112.91
²⁶⁸ Db	117.06	114.55	²⁶⁸ Sg	116.8	114.67	²⁶⁸ Bh	120.81	118.78	²⁶⁸ Hs	122.83	121.26	²⁶⁸ Mt	129.15	127.67
²⁶⁸ Ds	133.65	132.34	²⁶⁹ Db	119.15	116.40	²⁶⁹ Sg	119.82	117.25	²⁶⁹ Bh	121.48	119.38	²⁶⁹ Hs	124.59	122.88
²⁶⁹ Mt	129.31	127.48	²⁷⁰ Db	122.36	119.60	²⁷⁰ Sg	121.49	118.70	²⁷⁰ Bh	124.23	121.61	²⁷⁰ Hs	125.09	123.11
²⁷⁰ Mt	130.71	128.77	²⁷¹ Sg	124.76	121.91	²⁷¹ Bh	125.99	123.03	²⁷¹ Hs	127.77	125.28	²⁷¹ Mt	131.1	128.87
²⁷¹ Ds	135.95	133.96	²⁷² Sg	126.58	123.72	²⁷² Bh	128.79	125.88	²⁷² Hs	129.01	126.32	²⁷² Mt	133.58	130.66
²⁷² Ds	136.02	133.77	²⁷² Rg	142.77	141.05	²⁷³ Sg	130.02	127.17	²⁷³ Bh	130.63	127.66	²⁷³ Hs	131.97	129.12
²⁷³ Mt	134.51	131.66	²⁷³ Ds	138.38	135.43	²⁷³ Rg	142.64	140.84	²⁷⁴ Bh	133.71	130.74	²⁷⁴ Hs	133.49	130.60
²⁷⁴ Mt	137.16	134.12	²⁷⁴ Ds	139.18	136.09	²⁷⁴ Rg	144.62	142.11	²⁷⁵ Bh	135.69	132.98	²⁷⁵ Hs	136.62	133.73
²⁷⁵ Mt	138.63	135.54	²⁷⁵ Ds	141.62	138.47	²⁷⁵ Rg	145.26	142.67	²⁷⁶ Hs	138.29	135.48	²⁷⁶ Mt	141.21	138.24
²⁷⁶ Ds	142.54	139.51	²⁷⁶ Rg	147.49	144.65	²⁷⁶ Cp	150.35	148.08	²⁷⁷ Hs	141.49	138.34	²⁷⁷ Mt	142.77	139.95
²⁷⁷ Ds	145.23	142.26	²⁷⁷ Rg	148.17	145.62	²⁷⁷ Cp	152.43	150.00	²⁷⁸ Rg	145.6	142.55	²⁷⁸ Ds	146.28	143.46
²⁷⁸ Rg	150.43	147.97	²⁷⁸ Cp	152.91	150.85	²⁷⁸ 113	158.89	157.15	²⁷⁹ Mt	147.25	144.34	²⁷⁹ Ds	149.13	145.87
²⁷⁹ Rg	151.57	148.92	²⁷⁹ Cp	155.13	152.76	²⁷⁹ 113	159.24	157.77	²⁸⁰ Rg	153.83	150.83	²⁸⁰ Cp	155.7	153.10
²⁸⁰ 113	161.08	158.59	²⁸¹ Ds	153.24	149.32	²⁸¹ Cp	158.12	154.87	²⁸¹ 113	161.6	158.79	²⁸² Rg	157.53	153.79
²⁸² Cp	158.82	155.33	²⁸² 113	163.64	160.23	²⁸³ Rg	158.86	154.88	²⁸³ Cp	161.4	157.33	²⁸³ 113	164.48	160.73
²⁸⁴ 113	166.48	162.45	²⁸⁵ Cp	164.98	160.36	²⁸⁵ Fl	171.06	166.67	²⁸⁶ 113	169.73	165.14	²⁸⁶ Fl	171.61	167.19
²⁸⁷ 113	170.83	166.15	²⁸⁷ Fl	173.99	169.11	²⁸⁷ 115	177.64	173.46	²⁸⁸ 115	179.54	175.04	²⁸⁹ Fl	177.37	171.68
²⁸⁹ Lv	184.59	180.43	²⁹⁰ 115	182.55	177.53	²⁹⁰ Lv	185.03	180.79	²⁹¹ Lv	187.3	182.69	²⁹¹ 117	191.45	187.66
²⁹² 117	193.25	189.22	²⁹² Lv	190.48	185.08	²⁹³ 118	198.93	195.18	²⁹⁴ 117	196.04	191.68	²⁹⁴ 118	199.27	195.55
²⁹⁵ 118	201.43	197.36												