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On The Role of Nuclear Quantum Gravity In Understanding Nuclear Stability Range of Z = 2 to 118

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ABSTRACT

To understand the mystery of final unification, in our earlier publications, we proposed two bold concepts: 1) There exist three atomic gravitational constants associated with electroweak, strong and electromagnetic interactions. 2) There exists a strong elementary charge in such a way that its squared ratio with normal elementary charge is close to reciprocal of the strong coupling constant. In this paper we propose that, $\hbar c$ can be considered as a compound physical constant associated with proton mass, electron mass and the three atomic gravitational constants. With these ideas, an attempt is made to understand nuclear stability and binding energy. In this new approach, with reference to our earlier introduced coefficients k = 0.00642 and f = 0.00189, nuclear binding energy can be fitted with four simple terms having one unique energy coefficient. The two coefficients can be addressed with powers of the strong coupling constant. Classifying nucleons as 'free nucleons' and 'active nucleons', nuclear binding energy and stability can be understood. Starting from , number of isotopes seems to increase from 2 to 16 at and then decreases to 1 at For Z > = 84, lower stability seems to be, A_{lower} = (2.5 to 2.531)Z.

1. Introduction to Large Gravitational Coupling Constants

To understand the strong interaction, from 1974 to 1993, Tennakone, De Sabbata, Gasperini, Abdus Salam, Sivaram and K.P. Sinha [1-4] tried to introduce a large nuclear gravitational coupling constant. To understand weak interactions, in 2013, Roberto Onofrio [5] introduced a large electroweak gravitational coupling constant. In our 2011 and 2012 papers [6, 7] and recent papers [8-20], we introduced a very large electromagnetic gravitational coupling constant. In this context, we appeal that,

1) Success of any unified model depends on its ability to involve gravity in microscopic models.
2) Full-fledged implementation of gravity in microscopic physics must be able to:
   a) Estimate the ground state elementary particle rest masses of the three atomic interactions.
   b) Estimate the coupling constants of the three atomic interactions.
   c) Estimate the range of all interactions.
   d) Estimate the Newtonian gravitational constant.
3) As the root is unclear and unknown, to make it success or to have a full-fledged implementation, one may be forced to consider a new path that may be out-of-scope of the currently believed unsuccessful unified physics.
4) In our approach,
   a) We assign a different gravitational constant for each basic interaction.
   b) We consider proton and electron as the two characteristic building blocks of the four basic interactions.
   c) Finally, by eliminating the three atomic gravitational constants, we develop a characteristic relation for estimating the Newtonian gravitational constant.
   d) During this journey, without considering arbitrary numbers or coefficients, we come across many strange and interesting relations for estimating other atomic and nuclear coupling constants.
5) We strongly believe that, with further study, research and synthesizing the noticed relations in a systematic approach, actual essence of final unification can be understood.

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2. History and Current Status of Nuclear Binding Energy Scheme

With respect to nuclear binding energy and semi empirical mass formula (SEMF), the inverse problem framework [21], allows to infer the underlying model parameters from experimental observation, rather than to predict the observations from the model parameters. Recently, the ground-state properties of nuclei with Z=8 to 120 from the proton drip line to the neutron drip line have been investigated using the spherical relativistic continuum Hartree-Bogoliubov (RCHB) theory [22] with the relativistic density functional PC-PK1. In this context, in our recently published paper [8], we emphasized the fact that, physics and mathematics associated with fixing of the energy coefficients of SEMF are neither connected with residual strong nuclear force nor connected with strong coupling constant. N. Ghahramany and team members are constantly working on exploring the secrets of nuclear binding energy and magic numbers in terms of quarks [23, 24]. Very interesting point of their study is that - nuclear binding energy can be understood with two or three terms having single energy coefficient of the order of 10 MeV.

3. Three Bold Ideas

Even though celestial objects that show gravity are confirmed to be made up of so many atoms, so far scientists could not find any relation in between gravity and the atomic interactions. It clearly indicates that, there is something wrong in our notion of understanding or developing the unified physical concepts. To develop new and workable ideas, we emphasize that,

1) Whether particle's massive nature is due to electromagnetism or gravity or weak interaction or strong interaction or cosmic dust or something else, is unclear.
2) Without understanding the massive nature, it is not reasonable to classify the field created by any elementary particle.
3) All the four interactions seem to be associated with $(\hbar c)$.
4) Nobody knows the mystery of $(\hbar c)$ which seems to be a basic measure of angular momentum.
5) Nobody knows the mystery of existence, stability and behavior of 'proton' or 'electron'.
6) 'Mass' is a basic property of space-time curvature and basic ingredient of angular momentum.
7) Atoms are mainly characterized by protons and electrons.
8) 'Free neutron' is an unstable particle.

Based on the above points, we propose the following new and workable concepts.

Bold idea-1: The four basic interactions can be allowed to have four different gravitational constants.

Bold idea-2: There exists a strong elementary charge in such a way that its squared ratio with normal elementary charge is close to inverse of the strong coupling constant.

Bold idea-3: $(\hbar c)$ can be considered as a compound physical constant associated with proton mass, electron mass and the three atomic gravitational constants.

With the proposed first two [8-18] concepts, it seems possible to have many applications out of which nuclear stability and binding energy can be understood very easily. In addition to that, Newtonian gravitational constant can be estimated in a *verifiable approach* [18, 19, 20]. We appeal that, by considering the third bold idea, it may be possible to understand the combined role of the four gravitational constants in understanding the vector and tensor nature of fundamental forces and their interaction range.

4. Quantitative Relations

(1) Let, Electromagnetic gravitational constant =

$$G_e \cong 2.374335\times10^{37}\ \mathrm{m^3kg^{-1}sec^{-2}}$$

Nuclear gravitational constant =
$G_s \cong 3.329561\times10^{28}\mathrm{m^3kg^{-1}sec^{-2}}$

Weak gravitational constant =
$G_w \cong 2.909745\times10^{22}\ \mathrm{m^3kg^{-1}sec^{-2}}$

(2) $(\hbar c)$ can be considered as a compound physical constant,

$$\hbar c \cong \left(\frac{G_w}{G_s}\right)G_e m_p m_e \cong \sqrt{\left(G_s m_p m_e\right)\left(G_e m_e^2\right)} \cong \frac{\left(G_e^2 G_N\right)^{1/3} m_p^4}{m_e^2} \quad (1)$$

where G_N= Newtonian Gravitational constant.

(3) There exists a strong elementary charge (e_s) in such a way that,

$$\left.\begin{aligned}\frac{m_p}{m_e} &\cong \left(\frac{G_s m_p^2}{\hbar c}\right)\left(\frac{G_e m_e^2}{\hbar c}\right)\\ &\cong \left(\frac{e_s^2}{4\pi\varepsilon_0 G_s m_p^2}\right)\Big/\left(\frac{e^2}{4\pi\varepsilon_0 G_e m_e^2}\right)\end{aligned}\right\} \quad (2)$$

$$\rightarrow\left\{\begin{aligned}\frac{e_s^2}{e^2} &\cong \left(\frac{G_s m_p^3}{G_e m_e^3}\right) \cong \left(\frac{G_s m_p^2}{\hbar c}\right)^2 \cong \frac{1}{\alpha_s}\\ \frac{e_s}{e} &\cong \sqrt{\frac{G_s m_p^3}{G_e m_e^3}} \cong \left(\frac{G_s m_p^2}{\hbar c}\right) \cong \sqrt{\frac{1}{\alpha_s}}\end{aligned}\right\} \quad (3)$$

where, $\alpha_s \cong$ Strong coupling constant

Based on these relations,

$$e_s \cong 2.9463591e,\ \alpha_s \cong 0.1151937 \text{ and } \frac{1}{\alpha_s} \cong 8.681032$$

5. Understanding Proton-neutron Mean Stability with Three Atomic Gravitational Constants

In our recently published paper [8], we proposed the following semi empirical relations (4) to (7) for fitting nuclear stability and binding energy.

$$\left.\begin{aligned} s &\cong \left\{\left(\frac{e_s}{m_p}\right) \div \left(\frac{e}{m_e}\right)\right\} \cong 0.001605 \\ &\cong \sqrt{\frac{G_s m_p}{G_e m_e}} \cong \frac{G_s m_p m_e}{\hbar c} \cong \frac{\hbar c}{G_e m_e^2} \cong \frac{G_s^2}{G_e G_w} \cong \frac{m_p}{M_w} \end{aligned}\right\} \quad (4)$$

$$\text{where, } M_w \cong \sqrt{\hbar c / G_w} \cong 584.725 \text{ GeV}/c^2$$

Nuclear beta stability line can be explained with a relation of the form,

$$\begin{aligned} A_s &\cong Z + N_s \cong 2Z + s(2Z)^2 \cong 2Z + (4s)Z^2 \\ &\cong 2Z + kZ^2 \cong Z(2 + kZ) \\ &\text{where } k \cong 4s \cong 0.0064185 \end{aligned} \quad (5)$$

Here we would like to appeal that, estimated A_S can be considered as the mean stable mass number of Z. Here it is interesting to note that, in literature [25, 26], there exists a relation of the form, $N - Z \cong 0.006A^{5/3}$.

6. Understanding Nuclear Binding Energy

For $(Z \approx 3 \text{ to } 118)$, close to beta stability line, nuclear binding energy can be fitted with,

$$B_{A_s} \cong \left\{\left(1 - 0.00189\sqrt{ZN_s}\right)A_s - A_s^{1/3} - \left(\frac{Z}{N_s}\right)\right\} B_0 \quad (6)$$

See Figure 1. Dashed red curve plotted with relations (5) and (6) can be compared with the green curve plotted with the standard SEMF. For light, medium and heavy atomic nuclides, fit is reasonable.

Based on the proposed relations (4), (5) and (6) and with reference to Figure-1, we propose that,

(1) Nuclear unit radius can be expressed as,

$$R_0 \cong \frac{2G_s m_p}{c^2} \cong 1.239291 \text{ fm}$$

$$B_0 \cong \frac{e_s^2}{4\pi\varepsilon_0 R_0} \cong \frac{e_s^2}{8\pi\varepsilon_0 \left(G_s m_p / c^2\right)} \cong 10.09 \text{ MeV}$$

can be considered as the unique binding energy coefficient.

With reference to the recommended [27] up quark rest energy of 2.15 MeV and down quark rest energy of 4.7 MeV, it is quite interesting to note that, $\frac{\left[(2m_u + m_d)c^2 + (m_u + 2m_d)c^2\right]}{2} \cong 10.275 \text{ MeV}.$

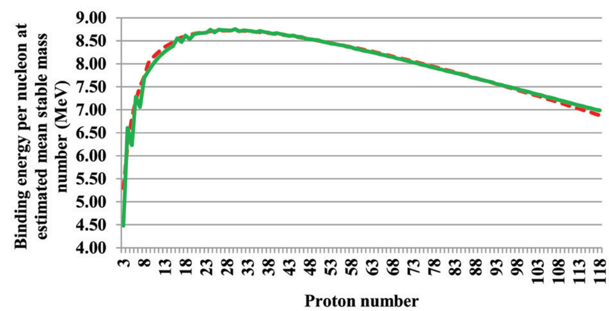

Figure 1: Binding energy per nucleon at estimated mean stable mass numbers of Z = 3 to 118.

(3) For increasing (Z, A), all nucleons will not involve in nuclear binding energy scheme.

(4) Nucleons that are not involving in nuclear binding energy scheme can be called as 'free nucleons' and can be represented by $A_f \cong k_f A\sqrt{ZN}$ where the coefficient $k_f \cong 0.00189$ can be called as 'Free nucleon number coefficient'. With reference to the semi empirical mass formula, quantitatively, $k_f \cong 2(a_c/a_a)^2 \cong 0.0018753$ where $a_c = 0.71$ MeV and $a_a = 23.21$ MeV.

(5) Nucleons that involve in nuclear binding energy scheme can be called as 'active nucleons' and can be represented by $A_a \cong A - A_f \cong A\left(1 - 0.00189\sqrt{ZN}\right)$.

(6) For $Z = 11$ to 84 when $(A_a - 2Z) \cong 0$, corresponding A seems to represent the possible existence of lower stability line.

(7) The ad-hoc coefficient 0.00189 somehow, seems to lie between $\{s \cong 0.0016 \text{ and } k \cong 0.0064\}$. With reference to electromagnetic interaction, we consider, $\left[k/\ln(30)\right] \cong 0.00189$ where 30 is a characteristic representation of atomic number below which strength of nuclear binding $[Z/30]^{\sqrt{k}}(1/\alpha_s) \cong [Z/30]^{0.08} \times 8.68$. From Z=30 onwards, strength of nuclear binding energy remains constant at $(1/\alpha_s) \cong 8.68$.

(8) Binding energy can be assumed to decrease with increasing radius**.**

(9) Decreasing proton-neutron ratio seems to play an interesting role in increasing binding energy.

(10) Considering isotopes, stable mass number plays an interesting role in estimating the binding energy of other stable and unstable isotopes in the form of $\left((A_s - A)^2 / A_s\right)$. It needs further investigation.

Above and below the stable mass numbers, binding energy can be *approximated* with,

$$B_A \cong \left\{\left(1-0.00189\sqrt{ZN}\right)A - A^{1/3} - \left(\frac{Z}{N}\right) - \frac{\left(A_s - A\right)^2}{A_s}\right\}B_0 \quad (7)$$

See Figure 2 for the estimated isotopic binding energy of Z=50. Dotted blue curve plotted with relations (5) and (7) can be compared with the green curve plotted with SEMF.

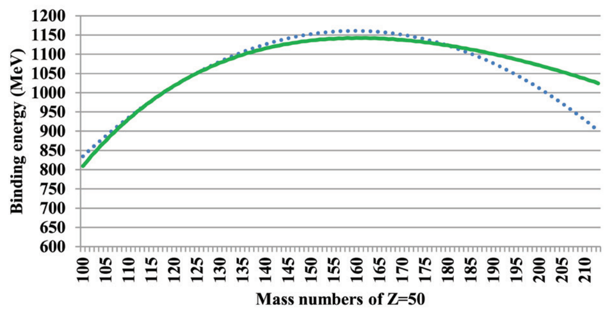

Figure 2: Isotopic binding energy of Z=50.

a) Based on Figures 1 and 2, it is possible to say that, Relations (5), (6) and (7) can also be given some priority in understanding nuclear binding energy scheme.

b) Estimated binding energy can also be compared with spherical relativistic continuum Hartree-Bogoliubov (RCHB) theory data [22] and Thomas-Fermi model (Table of nuclear masses, nsdssd.lbl.gov, 1994).

c) For $(N < Z)$ and $\left(N \approx Z\right)$ estimated binding energy seems to be increasing compared to SEMF estimation.

d) For $\left(A >> A_s\right)$, estimated binding energy seems to be decreasing compared to SEMF estimation.

7. Discussion on the Proposed Nuclear Binding Energy Scheme

(1) Nuclear binding energy can be understood with a single and unified energy coefficient.

(2) The new numbers (*s* and *k*) seem to play an interesting role in understanding nuclear stability and binding energy.

(3) With reference to stable mass number and similar to the famous relation $Z \cong A/\left(1.98 + 0.0153A^{2/3}\right)$, proton number can also be estimated with [11], $Z \cong \frac{A}{1+\sqrt{1+kA}} \cong \frac{\sqrt{kA+1}-1}{k}$.

(4) Considering a term of the form $\left(1-0.00189\sqrt{Z\sqrt{NN_s}}\right)$ or by modifying the terms, (Z/N) and $\left(\left(A_s - A\right)^2/A_s\right)$ binding energy for $\left(A << A_s\right)$ and $\left(A >> A_s\right)$ can be understood.

(5) Z = (2 to 118), close to stable mass numbers, binding energy [8] can also be *approximated* with,

$$\left.\begin{array}{l}
\text{For } Z < 30 \text{ and } A_s \cong Z\left(2+kZ\right), \\
\left(B_{A_s}\right) \cong \left(\frac{Z}{30}\right)^{0.08}\left\{A_s - \left[\left(0.00189N_s^2\right)+\frac{1}{2}\right]\right\}9.16 \text{ MeV} \\
\\
\text{For } Z \geq 30 \text{ and } A_s \cong Z\left(2+kZ\right), \\
\left(B_{A_s}\right) \cong \left\{A_s - \left[\left(0.00189N_s^2\right)+\frac{1}{2}\right]\right\}9.16 \text{ MeV}
\end{array}\right\} \quad (8)$$

$$\text{where, } \left\{\begin{array}{l}
\frac{e_s^2}{8\pi\varepsilon_0\left(G_s m_p/c^2\right)} - \left(\frac{e^2}{4\pi\varepsilon_0 R_0}\right) \cong 8.928 \text{ MeV} \\
\frac{e_s^2}{8\pi\varepsilon_0\left(G_s m_p/c^2\right)} - \frac{3}{5}\left(\frac{e^2}{4\pi\varepsilon_0 R_0}\right) \cong 9.395 \text{ MeV} \\
\text{and } \frac{8.928+9.395}{2} \cong 9.16 \text{ MeV}
\end{array}\right\}$$

See Figure 3. Dotted red curve plotted with relations (17) to (22) can be compared with the green curve plotted with the standard semi empirical mass formula (SEMF). For medium and heavy atomic nuclides, it is excellent. It seems that some correction is required for light and super heavy atoms.

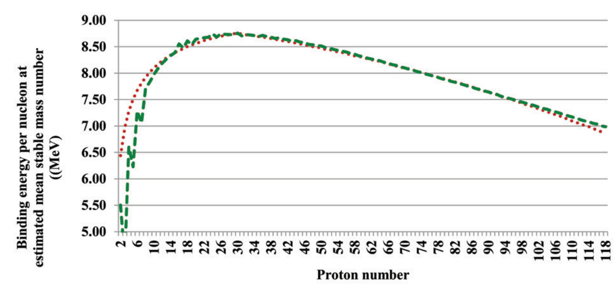

Figure 3: Binding energy per nucleon at estimated mean stable mass numbers of Z = 2 to 118.

(6) In case of Deuteron, there exists no strong interaction between proton and neutron [12, 13].

8.Understanding nuclear stability range

A) Basic observations and inferences

Based on the above points we noticed that, lower and upper stability lines of Z can be fitted with three relations. Back ground physics of the three relations can be understood with the following points.

1) Active nucleon number seems to play an interesting role in estimating lower stability line of lower Z and higher stability line of higher Z. The corresponding relation seems to be, $(A_a - 2Z) \cong 0$. Proposed relations (9) and (13) seem to be appropriate numerical solutions.
2) Condition for higher stability line of lower Z and lower stability line of higher Z seems to be $(A-2Z) \cong \frac{Z}{2}$ and $\frac{A}{Z} \cong 2.5 \cong \left(\frac{m_n - m_p}{m_e}\right) \cong 2 \cdot 531.$ to be explored with further study.
3) At Z = 83 or 84, nucleon-proton ratio seems to approach, $\frac{A}{Z} \cong 2.5$ (or) 2.531
4) As Z is increasing from 2 to 52, estimated isotopes number seems to increase from 2 to 16 respectively.
5) As Z is increasing from 53 to 84, estimated isotopes number seems to decrease from 16 to 1 respectively.
6) As Z is increasing from 84 to 118, estimated isotopes number seems to increase from 1 to 42 respectively.
7) At Z=84, estimated $(A_S)_{lower}$, $(A_S)_{mean}$ and $(A_S)_{upper}$ seems to be equal.
8) Z=84 seems to be a transition point for changeover of lower and upper stability lines. Clearly speaking,
   a) Lower stability line of Z<84, seems to become upper stability line of Z>84.
   b) Upper stability line of Z<84, seems to become lower stability line of Z>84
9) Best possible range of stable super heavy elements [28, 29, 30, 31] can be estimated with relations (10) and (13). See Table -1 for a possible comparison of long lived super heavy elements.
10) Considering even-odd corrections, accuracy can be improved.

Table 1: Comparison of long lived super heavy elements.

Proton number	Long lived mass number	Estimated lower stable mass number	Estimated mean stable mass number
100	257	253	264
101	258	256	267
102	259	258	271
103	266	261	274
104	267	263	277
105	268	266	281
106	269	268	284
107	270	271	288
108	269	273	291
109	278	276	294
110	281	278	298
111	282	281	301
112	285	283	305
113	286	286	308
114	289	289	311
115	290	291	315
116	293	294	318
117	294	296	322
118	294	299	325

B) Relations connected with lower, mean and upper stability lines of Z =2 to 118

a) Lower stability line

For, $Z \le 84$,

$$(A_s)_{lower} \cong 2Z + \left(3.4 \times \left(\frac{Z}{30}\right)^{2.5}\right) \quad (9)$$

where $\ln(30) \cong 3.4$

For, $Z > 84$,

$$(A_s)_{lower} \cong Z * 2.531 \quad (10)$$

where $\left(\frac{m_n - m_p}{m_e}\right) \cong 2.531$

b) Mean stability line

$$(A_s)_{mean} \cong 2Z + kZ^2 \quad (11)$$

where $k \cong 0.0064185$

c) Upper stability line

For, $Z \le 84$,

$$(A_s)_{upper} \cong Z * 2.531 \quad (12)$$

For, $Z > 84$,

$$(A_s)_{upper} \cong 2Z + \left(3.4 \times \left(\frac{Z}{30}\right)^{2.5}\right) \quad (13)$$

See the following Figures 4 and 5 and Table 2.

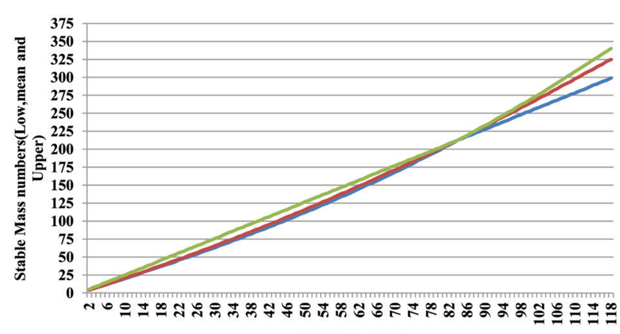

Figure 4: Estimated lower, mean and upper stable mass numbers of Z.

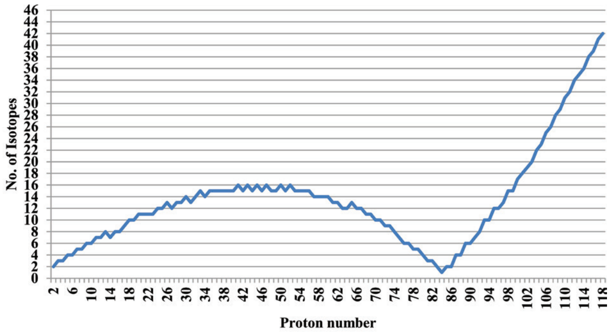

Figure 5: Estimated number of isotopes of Z.

Table 2: Estimated lower, mean and upper stable mass numbers of Z = 2 to 118.

Z	$(A_S)_{lower}$	$(A_S)_{mean}$	$(A_S)_{upper}$	Estimated No. of Isotopes
2	4	4	5	2
3	6	6	8	3
4	8	8	10	3
5	10	10	13	4
6	12	12	15	4
7	14	14	18	5
8	16	16	20	5
9	18	19	23	6
10	20	21	25	6
11	22	23	28	7
12	24	25	30	7
13	26	27	33	8
14	29	29	35	7
15	31	31	38	8
16	33	34	40	8
17	35	36	43	9
18	37	38	46	10
19	39	40	48	10
20	41	43	51	11
21	43	45	53	11
22	46	47	56	11
23	48	49	58	11
24	50	52	61	12
25	52	54	63	12
26	54	56	66	13
27	57	59	68	12
28	59	61	71	13
29	61	63	73	13
30	63	66	76	14
31	66	68	78	13
32	68	71	81	14
33	70	73	84	15
34	73	75	86	14
35	75	78	89	15
36	77	80	91	15
37	80	83	94	15
38	82	85	96	15
39	85	88	99	15
40	87	90	101	15
41	89	93	104	16
42	92	95	106	15
43	94	98	109	16
44	97	100	111	15
45	99	103	114	16
46	102	106	116	15
47	104	108	119	16
48	107	111	121	15
49	110	113	124	15
50	112	116	127	16
51	115	119	129	15
52	117	121	132	16
53	120	124	134	15
54	123	127	137	15
55	125	129	139	15
56	128	132	142	15
57	131	135	144	14
58	134	138	147	14
59	136	140	149	14
60	139	143	152	14
61	142	146	154	13
62	145	149	157	13
63	148	151	159	12
64	151	154	162	12
65	153	157	165	13
66	156	160	167	12
67	159	163	170	12
68	162	166	172	11
69	165	169	175	11
70	168	171	177	10
71	171	174	180	10
72	174	177	182	9

73	177	180	185	9
74	180	183	187	8
75	184	186	190	7
76	187	189	192	6
77	190	192	195	6
78	193	195	197	5
79	196	198	200	5
80	199	201	202	4
81	203	204	205	3
82	206	207	208	3
83	209	210	210	2
84	213	213	213	1
85	215	216	216	2
86	218	219	219	2
87	220	223	223	4
88	223	226	226	4
89	225	229	230	6
90	228	232	233	6
91	230	235	236	7
92	233	238	240	8
93	235	242	244	10
94	238	245	247	10
95	240	248	251	12
96	243	251	254	12
97	246	254	258	13
98	248	258	262	15
99	251	261	265	15
100	253	264	269	17
101	256	267	273	18
102	258	271	276	19
103	261	274	280	20
104	263	277	284	22
105	266	281	288	23
106	268	284	292	25
107	271	288	296	26
108	273	291	300	28
109	276	294	304	29
110	278	298	308	31
111	281	301	312	32
112	283	305	316	34
113	286	308	320	35
114	289	311	324	36
115	291	315	328	38
116	294	318	332	39
117	296	322	336	41
118	299	325	340	42

Conclusion

Understanding nuclear stability range in a quantum gravitational approach is challenging and most attractive issue. In this context, we tried our level best in presenting very simple and effective semi empirical formulae. The two proposed concepts, "Number of free nucleons = A_f" and "Number of active nucleons $=A_a$" can be given some consideration in understanding nuclear binding energy. The two proposed stability conditions, $\left(A_a - 2Z\right) \cong 0$ and $\left(A-2Z\right) \cong \left(Z/2\right)$ can be recommended for further investigation. By estimating the lower and upper stable mass numbers and with further study, possible number of isotopes of any proton number can be understood. With further investigation and by considering even-odd corrections, best possible range of long living super heavy elements can also be estimated.

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