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Research Article

Keywords: Strong interaction, Electroweak interaction, Ghahramany's integrated nuclear binding energy formula

Posted Date: August 30th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-855034/v1>

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STRONG AND WEAK INTERACTIONS IN GHAHRAMANY'S INTEGRATED NUCLEAR BINDING ENERGY FORMULA

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Abstract: By modifying Ghahramany's integrated nuclear binding energy formula with strong and weak interactions, it is possible to approximate the nuclear binding energy of isotopes with one unique energy coefficient and four terms. Considering even-odd corrections, shell corrections and other microscopic corrections, it seems possible to improve the accuracy with a clear physical basis. Based on our recent work and the proposed formula, we are very confident to say that, electroweak interaction plays a vital role in fixing the nuclear binding energy.

Keywords: Strong interaction; Electroweak interaction; Ghahramany's integrated nuclear binding energy formula;

1. Introduction

Semi empirical mass formulae (SEMF) are having a crucial role in understanding nuclear structure [1-4] and constitute a minimum of 5 terms with five different energy coefficients. Three major disadvantages of SEMF are: 1) Five energy coefficients are having arbitrary origin. 2) Role of strong and weak interactions is found to be missing. 3) Energy coefficients are having no particular relation with quarks and their structure. In this context, Ghahramany and team members [5-9] developed a very simple nuclear binding energy formula based on quark-gluon plasma. For increasing its effectiveness towards isotopes, in this paper, we try to include strong and weak interaction features [10,11] in Ghahramany's integrated nuclear binding energy formula (GINBEF).

2. Ghahramany's Integrated nuclear model

According to Ghahramany and team members, up and down quarks play a crucial role in understanding nuclear binding energy. Their unified views are:

- 1) The nuclear binding energy is of the order of 1% of the energy of the total rest mass of the constituent nucleons.
- 2) The binding energy depends upon the volume of the quark-gluon soup within the nuclei and is proportional to $3A$ where A is the mass number.
- 3) Due to the asymmetric distribution of up and down quarks and also the existence of the Coulomb force between them, binding energy depends upon terms such as $\frac{N^2 - Z^2}{Z}$.

For $A \geq 5$, different binding energy formulae proposed by Ghahramany and team members are as follows. In terms of up and down quarks,

$$BE \cong \left\{ 3A - \frac{(N^2 - Z^2) + \delta(N - Z)}{3Z} - 9 \right\} \left(\frac{330 \text{ MeV}}{100} \right) \quad (1)$$

where, $\begin{cases} \delta(N - Z) = 0 \text{ for } Z \neq N \\ \delta(N - Z) = 1 \text{ for } Z = N \end{cases}$

With reference to nucleon rest energy,

$$BE \cong \left\{ A - \frac{(N^2 - Z^2) + \delta(N - Z)}{3Z} - 3 \right\} \left(\frac{m_n c^2}{90 \text{ to } 100} \right) \text{ MeV} \quad (2)$$

where, $m_n c^2 = \text{Rest energy of nucleon}$
 $\begin{cases} \delta(N - Z) = 0 \text{ for } Z \neq N \\ \delta(N - Z) = 1 \text{ for } Z = N \end{cases}$

More advanced formula is,

$$BE \cong \left\{ A - \frac{(N^2 - Z^2) + \delta(N - Z)}{3(Z - k)} - 3 \right\} \left(\frac{A^{n+s} m_n c^2}{126(Z - k)} \right) \text{ MeV} \quad (3)$$

where, $m_n c^2 = \text{Rest energy of nucleon}$
 $n \cong 0.87 \text{ to } 0.88, k \cong \begin{cases} 2 \text{ for } Z \leq 118 \\ 0 \text{ for } Z > 118 \end{cases}$
 $s \cong \begin{cases} 0.0003 \text{ for even } (N, Z) \\ -0.0003 \text{ for odd } (N, Z) \end{cases}$

3. Understanding the role of electroweak interaction in nuclear binding energy scheme

With reference to strong and weak interactions in our recently published papers, we have developed a simple formula for estimating nuclear binding energy with one unique coefficient of magnitude 10.1 MeV. In this paper, we made an attempt to include strong and weak interactions in GINBEF. It may be noted that, single variable binding energy constant and 3 simple terms play an interesting role in GINBEF. By considering strong and weak interactions, we have improved the workability of GINBEF applicable for isotopes and it needs further study with respect to $Z \approx N$.

By considering electroweak interaction, in nuclear binding energy scheme, we noticed that,

- 1) Unique binding energy coefficient is interconnected with basic nuclear potential, reciprocal of the strong coupling constant [12] and up and down quark rest masses [12]. (See section 9).
- 2) All the nucleons are not participating in nuclear binding energy.

- 3) Electroweak interaction plays a vital role in deciding the number of non-participating nucleons in the form of $[1 + 0.0019A\sqrt{NZ}]$.
- 4) Electroweak interaction decides the stable mass numbers of Z in the form of $A_s \cong 2Z + 0.0016(2Z)^2 \cong 2Z + 0.0064Z^2$.
- 5) With reference to pions and electro weak bosons, number 0.0016 can be expressed with a relation of the form, $\left(\frac{\sqrt{(m_\pi c^2)^0 (m_\pi c^2)^+}}{\sqrt{(m_z c^2)^0 (m_z c^2)^+}}\right) \cong \left(\frac{\sqrt{134.98 \times 139.57} \text{ MeV}}{\sqrt{80379.0 \times 91187.6} \text{ MeV}}\right) \cong 0.0016032$.
- 6) Stable mass number of Z plays an interesting role in reducing the binding energy of isotopes in the form of $\frac{(A_s - A)^2}{A_s}$.
- 7) Binding energy decreases with increasing surface area and increasing radius with an effective term of the form $(A^{2/3} / A^{1/3}) \cong A^{1/3}$.

Binding energy can be approximated with a relation of the form,

$$BE \cong \left\{ A - [1 + 0.0019A\sqrt{NZ}] - A^{1/3} - \frac{(A_s - A)^2}{A_s} \right\} (10.1 \text{ MeV}) \quad (4)$$

By replacing the number 0.0019 with 0.0016, binding energy can be approximated with a relation of the form,

$$BE \cong \left\{ A - A^{1/3} - \frac{(A_s - A)^2}{A_s} \right\} (10.1 \text{ MeV}) - [1 + 0.0016A\sqrt{NZ}] (11.9 \text{ MeV}) \quad (5)$$

4. On the role of electroweak interaction in Integrated nuclear binding energy formula

Based on the above relations, we make an attempt to include strong and weak interactions in GINBEF. For $Z \geq 3$, it can be expressed in the following way.

$$BE \cong \left\{ A - [0.00173\sqrt{ZN}\sqrt{AA_s}] - \left[\left(0.118 \frac{(N^2 - Z^2)}{\sqrt{AA_s}} \right) + \left(\frac{(A - A_s)^2}{\sqrt{AA_s}} \right) \right] - \left[\sqrt{\frac{A}{Z}} + \frac{\sqrt{A}}{2} \right] \right\} 10.3 \text{ MeV} \quad (6)$$

$$\text{where } A_s \cong 2Z + 0.0064Z^2$$

With reference to various semi empirical mass formulae and with trial & error we have developed this relation. It is having many advantages compared to Ghahramany's integrated nuclear model. In this relation,

- 1) Second term can be considered as a consequence of electroweak interaction.
- 2) Third term can be considered as a consequence of Coulombic and Asymmetry.
- 3) Fourth term can be considered as a correction factor associated with neutron-proton ratio.

As a whole, accuracy depends on two numbers 0.00173 and 0.118, one energy coefficient of 10.3

MeV and selection of stable mass number of Z. With a computer program and fitting the estimated data with actual binding energies, things can be improved. By considering even-odd corrections, shell corrections and other microscopic corrections, relation (6) can be reviewed and refined with a clear physical background. See Table 1 for the binding energy of isotopes of Z=50. To compare the data prepared with relations (4), (5) and (6), we have taken the following three semi empirical mass formulae as references.

$$BE_{\text{Ref1}} \equiv \left\{ \left[(A \times 15.36) \right] - \left[(A^{2/3} \times 16.32) \right] - \left[\left(\frac{Z^2}{A^{1/3}} \right) 0.6929 \right] \right. \\ \left. - \left[\frac{((A/2) - Z)^2}{A} \times 90.46 \right] \pm \left(\frac{11.32}{\sqrt{A}} \right) \right\} \text{ MeV} \quad (7)$$

Ref. → <https://fddocuments.in/document/nuclear-and-particle-physics.html>

$$BE_{\text{Ref2}} \equiv \left(a_v * A \right) - \left(a_s * A^{2/3} \right) - \left(a_c * \frac{Z * (Z-1)}{A^{1/3}} \right) - \left(a_a * \frac{(A-2Z)^2}{A} \right) \pm \left(\frac{a_p}{\sqrt{A}} \right) \\ \text{where } \begin{cases} a_v \cong 15.8 \text{ MeV}; a_s \cong 18.3 \text{ MeV}; a_c \cong 0.714 \text{ MeV}; \\ a_a \cong 23.2 \text{ MeV}; a_p \cong 12.0 \text{ MeV}; \end{cases} \quad (8)$$

Ref. → https://en.wikipedia.org/wiki/Semi-empirical_mass_formula

$$BE_{\text{Ref3}} \equiv \left(a_v * x * A \right) - \left(a_s * x * A^{2/3} \right) - \left(a_c * \frac{Z^2}{A^{1/3}} \right) + \left(a_{pr} * \frac{Z^2}{A} \right) \pm \left(\frac{a_p}{\sqrt{A}} \right) \\ \text{where } \begin{cases} x \cong \left[1 - 1.79 \left(\frac{N-Z}{A} \right)^2 \right] \\ a_v \cong 15.677 \text{ MeV}; a_s \cong 18.56 \text{ MeV}; a_c \cong 0.717 \text{ MeV}; \\ a_{pr} \cong 1.211 \text{ MeV}; a_p \cong 11.0 \text{ MeV}; \end{cases} \quad (9)$$

Ref. → <http://oregonstate.edu/instruct/ch374/ch418518/lecture3-1.pdf>

Table 1: Estimated nuclear binding energy of isotopes of Z=50

Z=50	N	A	Estimated stable mass number	Ref_1.BE (MeV) Relation-7	Ref_2.BE (MeV) Relation-8	Ref_3.BE (MeV) Relation-9	Est_1 BE (MeV) Relation-4	Est_2 BE (MeV) Relation-5	Est_3 BE (MeV) Relation-6
50	50	100	116	812.3	810.1	813.0	834.8	833.7	843.5
50	51	101	116	825.2	823.1	825.7	845.5	844.5	854.0
50	52	102	116	839.9	838.0	840.2	856.0	855.0	864.2
50	53	103	116	852.0	850.1	852.1	866.4	865.4	874.2
50	54	104	116	865.8	864.1	865.7	876.6	875.6	884.0
50	55	105	116	877.0	875.4	876.9	886.6	885.6	893.6
50	56	106	116	890.0	888.6	889.8	896.4	895.4	903.0
50	57	107	116	900.5	899.1	900.2	906.0	905.0	912.1

50	58	108	116	912.7	911.5	912.4	915.4	914.5	921.1
50	59	109	116	922.4	921.2	922.1	924.7	923.8	929.8
50	60	110	116	933.9	932.8	933.6	933.8	932.9	938.3
50	61	111	116	942.9	941.9	942.7	942.6	941.8	946.7
50	62	112	116	953.8	952.8	953.6	951.4	950.5	954.8
50	63	113	116	962.1	961.1	962.0	959.9	959.0	962.8
50	64	114	116	972.3	971.4	972.3	968.2	967.4	970.5
50	65	115	116	980.0	979.1	980.1	976.4	975.6	978.1
50	66	116	116	989.5	988.8	989.8	984.4	983.6	985.5
50	67	117	116	996.7	995.9	997.1	992.2	991.4	992.6
50	68	118	116	1005.6	1004.9	1006.1	999.8	999.0	999.7
50	69	119	116	1012.2	1011.4	1012.9	1007.2	1006.5	1006.5
50	70	120	116	1020.6	1019.9	1021.4	1014.5	1013.7	1013.1
50	71	121	116	1026.7	1025.9	1027.7	1021.5	1020.8	1019.6
50	72	122	116	1034.5	1033.8	1035.7	1028.4	1027.7	1025.9
50	73	123	116	1040.1	1039.3	1041.5	1035.1	1034.4	1032.0
50	74	124	116	1047.4	1046.7	1049.0	1041.6	1041.0	1038.0
50	75	125	116	1052.5	1051.6	1054.3	1048.0	1047.3	1043.8
50	76	126	116	1059.3	1058.5	1061.3	1054.1	1053.5	1049.4
50	77	127	116	1063.9	1063.1	1066.1	1060.1	1059.5	1054.8
50	78	128	116	1070.3	1069.5	1072.7	1065.9	1065.3	1060.1
50	79	129	116	1074.5	1073.5	1077.1	1071.5	1070.9	1065.3
50	80	130	116	1080.5	1079.5	1083.3	1076.9	1076.3	1070.2
50	81	131	116	1084.2	1083.2	1087.3	1082.1	1081.6	1075.1
50	82	132	116	1089.8	1088.7	1093.0	1087.2	1086.7	1079.7
50	83	133	116	1093.1	1091.9	1096.6	1092.1	1091.6	1084.2
50	84	134	116	1098.3	1097.0	1101.9	1096.8	1096.3	1088.6
50	85	135	116	1101.2	1099.9	1105.1	1101.3	1100.8	1092.8
50	86	136	116	1106.0	1104.6	1110.0	1105.6	1105.1	1096.8
50	87	137	116	1108.6	1107.1	1112.9	1109.7	1109.3	1100.7
50	88	138	116	1113.0	1111.5	1117.4	1113.7	1113.3	1104.5
50	89	139	116	1115.3	1113.6	1119.9	1117.5	1117.1	1108.1
50	90	140	116	1119.3	1117.6	1124.1	1121.1	1120.7	1111.5
50	91	141	116	1121.2	1119.4	1126.3	1124.5	1124.1	1114.9
50	92	142	116	1124.9	1123.0	1130.1	1127.7	1127.4	1118.0
50	93	143	116	1126.5	1124.5	1132.0	1130.8	1130.5	1121.1
50	94	144	116	1129.9	1127.8	1135.5	1133.7	1133.3	1124.0
50	95	145	116	1131.2	1129.0	1137.0	1136.3	1136.0	1126.7
50	96	146	116	1134.3	1131.9	1140.2	1138.8	1138.6	1129.4
50	97	147	116	1135.3	1132.8	1141.4	1141.2	1140.9	1131.9
50	98	148	116	1138.0	1135.5	1144.3	1143.3	1143.1	1134.2
50	99	149	116	1138.8	1136.1	1145.2	1145.3	1145.0	1136.4
50	100	150	116	1141.3	1138.5	1147.8	1147.0	1146.8	1138.5
50	101	151	116	1141.7	1138.8	1148.5	1148.6	1148.5	1140.5
50	102	152	116	1143.9	1140.9	1150.8	1150.1	1149.9	1142.3
50	103	153	116	1144.2	1140.9	1151.1	1151.3	1151.1	1144.0
50	104	154	116	1146.1	1142.8	1153.2	1152.3	1152.2	1145.6
50	105	155	116	1146.1	1142.5	1153.3	1153.2	1153.1	1147.0
50	106	156	116	1147.7	1144.1	1155.0	1153.9	1153.8	1148.3
50	107	157	116	1147.5	1143.7	1154.9	1154.4	1154.3	1149.5
50	108	158	116	1148.9	1145.0	1156.4	1154.7	1154.6	1150.6
50	109	159	116	1148.4	1144.3	1156.0	1154.8	1154.8	1151.6

50	110	160	116	1149.6	1145.4	1157.2	1154.8	1154.8	1152.4
50	111	161	116	1148.9	1144.5	1156.6	1154.6	1154.6	1153.1
50	112	162	116	1149.8	1145.3	1157.6	1154.2	1154.2	1153.7
50	113	163	116	1148.9	1144.2	1156.8	1153.6	1153.6	1154.1
50	114	164	116	1149.7	1144.8	1157.5	1152.8	1152.9	1154.5

5. Second term of relation (6)

We noticed that, reduction of binding energy is greatly influenced by electroweak interaction. Clearly speaking, second term plays a major role in reducing nuclear binding energy compared to other terms. This can be confirmed with relations (4) and (5). Number of non-participating nucleons seems to increase with increasing mass number. For ${}_{92}\text{U}^{238}$, number of non-participating nucleons are 48 and corresponding reduction in binding energy is 490 MeV. This is approximately 27% of total binding energy.

6. First part of the third term of relation (6)

Considering the third term, it constitutes two sub terms. First sub term is $\left(0.118 \frac{(N^2 - Z^2)}{\sqrt{AA_s}}\right)$ and the second sub term is $\left(\frac{(A - A_s)^2}{\sqrt{AA_s}}\right)$. First sub term is almost similar to the Ghahramany's proposed second term, $\frac{(N^2 - Z^2)}{3Z}$. Multiplying and dividing relation (1) by 3 and ignoring $\delta(N - Z)$, it is possible to re-express it as,

$$BE \cong \left\{ A - \frac{(N^2 - Z^2)}{9Z} - 3 \right\} (9.9 \text{ MeV}) \quad (10)$$

It may be noted that, $\frac{(N^2 - Z^2)}{9Z} \cong \frac{1}{9} \left[\frac{(N^2 - Z^2)}{Z} \right] \cong 0.11\bar{1} \left[\frac{(N^2 - Z^2)}{Z} \right]$. The number $\left(\frac{1}{9}\right) \cong 0.11\bar{1}$ almost resembles the currently believed strong coupling constant [11,12], $\alpha_s \cong 0.118$. Keeping this coincidence in view we tried to replace $\left(\frac{1}{9}\right)$ with α_s . By doing so, it is possible to bring strong interaction characteristics into nuclear binding energy scheme. It needs a serious review.

7. Second part of the third term of relation (6)

It is quite interesting to note that, second sub term of the third term plays a nice role in reducing the binding energy of isotopes of Z about its stable mass number. Clearly speaking, on both side of the selected stable mass number of Z, it helps in curve bending with reference to mainstream semi empirical mass formulae.

8. Fourth term of relation (6)

With trial-error, we have introduced the fourth term in place of the third term of the Ghahramany's integrated nuclear model. Even though, its contribution in reducing binding energy of medium and heavy atomic nuclides is minute, for light atomic nuclides, its role is considerable. It needs a review and refinement with respect to actual binding energy.

9. Discussion on the binding energy coefficient

Unique binding energy coefficient can be understood in two possible ways. One way is based on the basic nuclear potential and reciprocal of the strong coupling constant[12]. Second way is to consider the average rest energy of up and down quarks [12].

Method-1: Considering nuclear potential and strong coupling constant, unique binding energy coefficient can be expressed as,

$$B_0 \cong \left(\frac{1}{\alpha_s} \right) \frac{e^2}{4\pi\epsilon_0 R_0} \cong (10.0 \text{ to } 10.4) \text{ MeV} \quad (11)$$

where, $\begin{cases} \alpha_s \cong 0.115 \text{ to } 0.12 \\ R_0 \cong 1.20 \text{ fm} \end{cases}$

Method-2: Considering up and down quark masses, unique binding energy coefficient can be expressed as,

$$B_0 \cong \left. \begin{aligned} & \frac{(2m_u c^2 + m_d c^2) + (m_u c^2 + 2m_d c^2)}{2} \\ & \cong \frac{3}{2} (m_u c^2 + m_d c^2) \cong 10.26 \text{ MeV} \\ & \text{where } \begin{cases} m_u c^2 \cong 2.16^{+0.49}_{-0.26} \text{ MeV} \\ m_d c^2 \cong 4.68^{+0.48}_{-0.17} \text{ MeV} \end{cases} \end{aligned} \right\} \quad (12)$$

Combining relations (11) and (12),

$$\alpha_s \cong \frac{2e^2}{12\pi\epsilon_0 R_0 (m_u + m_d) c^2} \quad (13)$$

$$R_0 \cong \left(\frac{1}{\alpha_s} \right) \frac{2e^2}{12\pi\epsilon_0 (m_u + m_d) c^2} \quad (14)$$

10. Conclusion

Ghahramany's integrated nuclear binding energy formula can be modified to include strong and electroweak interaction features with a single energy coefficient. Based on relations (4), (5) and (6) and data presented in Table 1, we are very confident to say that, electroweak interaction plays a vital role in fixing nuclear binding energy and it is absolutely possible to understand nuclear binding energy with one unique energy coefficient. In this context, to explore the ground reality,

we appeal the science community to look into these kinds of unified and simplified nuclear binding energy models.

Conflict of Interest

The authors declare no conflict of interest in this paper.

Data Availability statement

Energy coefficients of relations (7), (8) and (9) can be obtained from the following URL's.

- 1) Relation-7: <https://documents.in/document/nuclear-and-particle-physics.html>
- 2) Relation-8: https://en.wikipedia.org/wiki/Semi-empirical_mass_formula
- 3) Relation-9: <http://oregonstate.edu/instruct/ch374/ch418518/lecture3-1.pdf>

Acknowledgements

Authors are very much thankful to Dr. N. Ghahramany and team for their intuitive and heuristic contributions in this most advanced field of nuclear research. Author Seshavatharam is indebted to professors shri M. Nagaphani Sarma, Chairman, shri K.V. Krishna Murthy, founder Chairman, Institute of Scientific Research in Vedas (I-SERVE), Hyderabad, India and Shri K.V.R.S. Murthy, former scientist IICT (CSIR), Govt. of India, Director, Research and Development, I-SERVE, for their valuable guidance and great support in developing this subject.

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