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Understanding Nuclear Binding Energy with Strong and Electroweak Coupling Constants

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Abstract: At nuclear scale, we present three heuristic relations pertaining to strong and electroweak coupling constants. With these relations, close to beta stability line, it is possible to study nuclear binding energy with a single energy coefficient of magnitude $\left(\frac{1}{\alpha_s}\right)\left[\frac{e^2}{4\pi\varepsilon_0 R_0}\right] \approx 10.0$ MeV. With reference to up and down quark masses, it is also possible to interpret that, nuclear binding energy is proportional to the mean mass of $\left[(2m_u + m_d) \text{ and } (m_u + 2m_d)\right] \approx 10.0$ MeV.

Keywords: nuclear charge radius; strong coupling constant; Fermi's weak coupling constant; nuclear binding energy coefficient

1. Introduction

The modern theory of strong interaction is Quantum chromodynamics (QCD) [1]. It explores baryons and mesons in broad view with 6 quarks and 8 gluons. According to QCD, the four important properties of strong interaction are: 1) color charge;2) confinement; 3) asymptotic freedom [2];4) short-range nature($<10^{-15}$ m). Color charge is assumed to be responsible for the strong force to act on quarks via the force carrying agent, gluon. Experimentally it is well established that, strength of strong force depends on the energy of the interaction or the distance between particles. At lower energies or longer distances: a) color charge strength increases; b) strong force becomes 'stronger'; c) nucleons can be considered as fundamental nuclear particles and quarks seem to be strongly bound within the nucleons leading to 'Quark confinement'. At high energies or short distances: a) color charge strength decreases; b) strong force gets 'weaker';3) colliding protons generate 'scattered free quarks' leading to 'Quark Asymptotic freedom'. Based on these points, low energy nuclear scientists assume 'strong interaction' as a strange nuclear interaction associated with binding of nucleons and its implications were not considered. High energy nuclear scientists consider nucleons as composite states of quarks and try to understand the nature and strength of strong interaction (α_s) at sub nuclear level. According to QCD, (α_s) decreases with increasing interaction energy. By definition, at low energy scales, $\alpha_s \cong 1$ and by experiments and observations, at 80 to 90 GeV energy scales, $\alpha_s \cong 0.1186$.

At this juncture, one important question to be answered and reviewed at basic level is: **How to understand nuclear interactions in terms of sub nuclear interactions?** Unfortunately, 1) At 1.2 fm scale, there is no practical evidence or applications for the basic definition of $\alpha_s \cong 1$. 2) With current concepts of QCD, one cannot explain the observed nuclear binding energy scheme. 3) Famous nuclear models like, Liquid drop model and Fermi gas model [3-6] are lagging in answering this question. To find a way, we would like to suggest that, by implementing the 'strong coupling constant' of magnitude 0.1186 - in low energy nuclear physics, nuclear charge radius, Fermi's weak coupling constant and strong coupling constant can be studied in a unified picture. Proceeding further, close to beta stability line, nuclear binding energy can be addressed with a single energy coefficient of magnitude (8.9 to 10.0) MeV [7-10].

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2. Three heuristic relations

In this section we present three heuristic relations. We believe that, they are having deep inner meaning at very fundamental level and they can be derived with further research.

Relation-1:

$$R_0 \cong \left(\frac{m_p}{m_e}\right)\sqrt{\frac{F_W}{\hbar c}} \cong 1.23742 \text{ fm} \tag{1}$$

Here, F_W =Fermi's weak coupling constant= 1.43586×10^{-62} J.m^3 ; m_e = Rest mass of electron; m_p = Rest mass of proton; R_0 = Nuclear charge radius.

Relation-2:

$$R_0 \cong \left(\frac{1}{\sqrt{\alpha_s}}\right)\left[\frac{\hbar}{m_p c}+\frac{\hbar}{m_p c}\right] \cong \left(\frac{1}{\sqrt{\alpha_s}}\right)\left[\frac{2\hbar}{m_p c}\right] \cong 1.2214 \text{ fm} \tag{2}$$

m_p = Rest mass of proton; m_n = Rest mass of neutron; α_s = Strong coupling constant.

Relation-3: From relations (1) and (2),

$$\alpha_s F_W \cong \frac{4\hbar^3 m_e^2}{m_p^4 c} \tag{3}$$

Based on relation (3),

$$F_W \cong \frac{4\hbar^3 m_e^2}{\alpha_s m_p^4 c} \cong 1.399\times10^{-62} \text{ J.m}^3 \tag{4}$$

$$\alpha_s \cong \frac{4\hbar^3 m_e^2}{m_p^4 c F_W} \cong \left(\frac{m_e}{m_p}\right)^2\left(\frac{4\hbar^3}{m_p^2 c F_W}\right) \cong 0.115543 \tag{5}$$

Based on this relation and considering relativistic energy of proton, it is possible to show that, $\alpha_s \propto \left\{\left[1-(v/c)^2\right]/m_p^2\right\}$. Qualitatively, this kind of observation seems to be in-line with modern QCD concepts.

3. Discussion

In our previous publications [7,8], we proposed that, close to the beta stability line, nuclear binding energy can be addressed with a single energy coefficient, B_0 of the order of 10.0 MeV . With the proposed relations, it can be expressed as:

$$\begin{aligned} B_0 &\cong \left(\frac{1}{\alpha_s}\right)\left[\frac{e^2}{4\pi\varepsilon_0 R_0}\right] \cong \left(\frac{1}{\alpha_s}\right)\left(\frac{m_e}{m_p}\right)\left(\frac{e^2}{4\pi\varepsilon_0}\right)\sqrt{\frac{\hbar c}{F_W}} \\ &\cong \frac{e^2 m_p^3 c^2}{16\pi\varepsilon_0 \hbar^2 m_e}\sqrt{\frac{F_W}{\hbar c}} \cong 10.0715 \text{ MeV} \end{aligned} \tag{6}$$

With this energy unit, close to beta stability line, stable mass number of Z can be addressed with,

$$\left.\begin{aligned} A_s &\cong (2Z)+(\beta Z)^2 \\ N_s &\cong Z+(\beta Z)^2 \end{aligned}\right\} \quad (7)$$

where,

$$\left.\begin{aligned} \beta &\cong \left(\frac{3}{5}\right)\left[\frac{e^2}{4\pi\varepsilon_0 R_0}\right] \div \left\{\left(\frac{1}{\alpha_s}\right)\left[\frac{e^2}{4\pi\varepsilon_0 R_0}\right]-\left[\frac{e^2}{4\pi\varepsilon_0 R_0}\right]\right\} \\ &\cong \frac{0.71\text{ MeV}}{(10.07-1.188)\text{ MeV}} \cong \frac{0.71\text{ MeV}}{8.89\text{ MeV}}\left[\frac{3}{5}\left(\frac{\alpha_s}{1-\alpha_s}\right)\right] \cong 0.08 \end{aligned}\right\} \quad (8)$$

Based on the new integrated model proposed by N. Ghahramany et al [9,10] and with reference to relation (7), it is possible to show that, $Z \cong (40 \text{ to } 83)$, close to the beta stability line,

$$(B)_{A_s} \cong \left[A_s - \left(\frac{N_s^2 - Z^2}{3Z}\right)\right] \times 9.5\text{ MeV} \cong \left[A_s - \left(\frac{\beta^2 Z A_s}{3}\right)\right] \times 9.5\text{ MeV} \quad (9)$$

where, $\left[\frac{N_s^2 - Z^2}{Z}\right] \cong \beta^2 Z A_s$. Based on this strange and simple relation and with reference to our recent publications [7,8] and first four terms of the semi empirical mass formula (SEMF), close to the beta stability line, for $(Z = 2 \text{ to } 100)$, it is possible to show that,

$$\begin{aligned} (B)_{A_s} &\cong \left[A_s - A_s^{1/3} - \frac{\beta^2 A_s \sqrt{N_s Z}}{3.42} - 1\right] \times 10.07\text{ MeV} \\ \text{where, } &\left(\frac{\beta^2}{3.42}\right) \approx \alpha_s\left(\frac{a_c}{2a_a}\right). \end{aligned} \quad (10)$$

It is for further study. According to PDG data [11] , up quark mass is $2.15\text{ MeV}/c^2$ and down quark mass is 4.7 MeV/c^2. With reference to proton and neutron, for these two basic quark masses,

$$\left.\begin{aligned} &\frac{(2m_u+m_d)+(m_u+2m_d)}{2} \cong 10.275\text{ MeV}, \\ &\sqrt{(2m_u+m_d)(m_u+2m_d)} \cong 10.2\text{ MeV} \\ &\text{and } \frac{2(2m_u+m_d)(m_u+2m_d)}{[(2m_u+m_d)+(m_u+2m_d)]} \cong 10.12\text{MeV} \end{aligned}\right\} \quad (11)$$

Based on relations (10) and (11), it is also possible to interpret that, nuclear binding energy is proportional to mean mass of $[(2m_u+m_d),(m_u+2m_d)]$. This idea seems to be in line with the new model proposed by N. Ghahramany et al in 2011 [12].

With reference to SEMF, close to the beta stability line, it is also possible to show that,

$$\frac{(A_s - 2Z)^2}{A_s} \cong \left(\beta^4 A_s N_s \sqrt{Z}\right) \quad (12)$$

Let, $\left\{\begin{array}{l} a_v \cong a_s \cong a_a \approx 14.8 \text{ MeV} \approx (3/2)\times 10.0 \text{ MeV} \\ \text{and } \; a_c \cong 0.71 \text{ MeV} \end{array}\right\}.$

If so,

$$(B)_{A_s} \approx \left[A_s - A_s^{2/3} - 0.0473\left[\frac{Z(Z-1)}{A_s^{1/3}}\right] - \left(\beta^4 A_s N_s \sqrt{Z}\right)\right] \times 14.8 \text{ MeV} \tag{13}$$

In comparison with SEMF, by replacing A_s with A in relation (13) and by considering a multiplication factor of the kind $\left(\frac{A_s}{A}\right)^{1-(Z/A)}$ associated with each term, binding energy of A can be estimated approximately. For $Z = 50$ and $A = 100$ to 136, estimated binding energy range is (829 to 1120) MeV and can be compared with reference binding energy[4] range of (806 to 1105) MeV.

For relations (10) and (13), see figure 1 (red and violet curves respectively) for the estimated binding energy per nucleon close to beta stability line of Z= 2 to 100 compared with first four terms of the semi empirical mass formula (Green curve) where $a_v \cong 15.77$ MeV, $a_s \cong 18.34$ MeV, $a_a \cong 23.2$ MeV and $a_c \cong 0.71$ MeV.

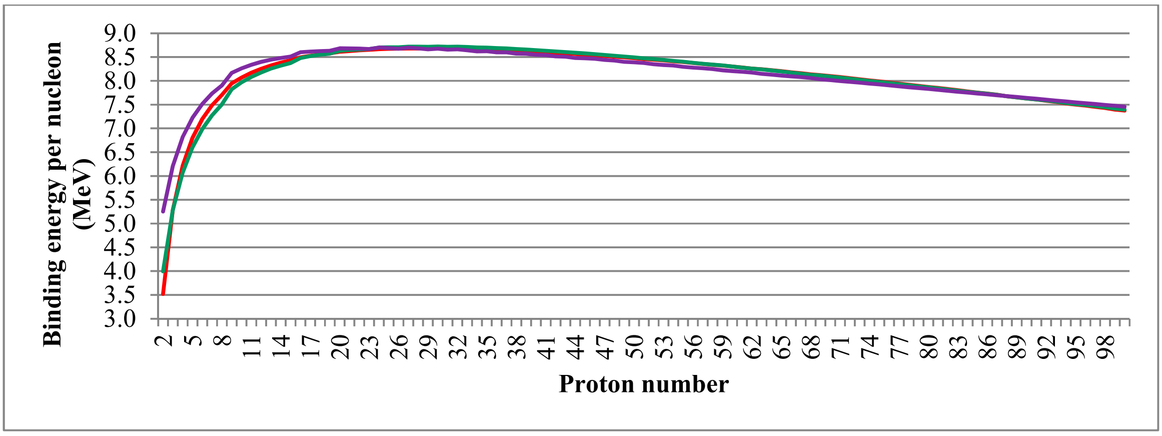

Figure 1: Binding energy per nucleon close to beta stability line of Z= 2 to 100

4. Conclusions

Based on the proposed relations (1) to (12), beta decay and existence of massive electroweak bosons, we would like to suggest that, unidentified physics is happening at nuclear scale and needs a serious study at basic level.

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