Baryon number violation from confining New Physics

Mathew Thomas Arun
School of Physics, Indian Institute of Science Education and Research Thiruvananthapuram, Vithura, Kerala, 695551, India

e-Print: 2204.06484 [hep-ph]

Nature has eluded all our direct searches for New Physics (NP) so far, but it has bestowed us with a few indirect hints.

Most prominent among this is the observed baryon to photon ratio implying a baryon-anti-baryon asymmetry, for which, a crucial ingredient is the violation of baryon number.

Though complex models can be formulated to study the baryon number violating effects, an uncluttered presentation of the mechanism is possible with a minimal design of the linear moose, where U(1) global symmetries are linked together by confining non-abelian gauge groups as shown in Fig.1

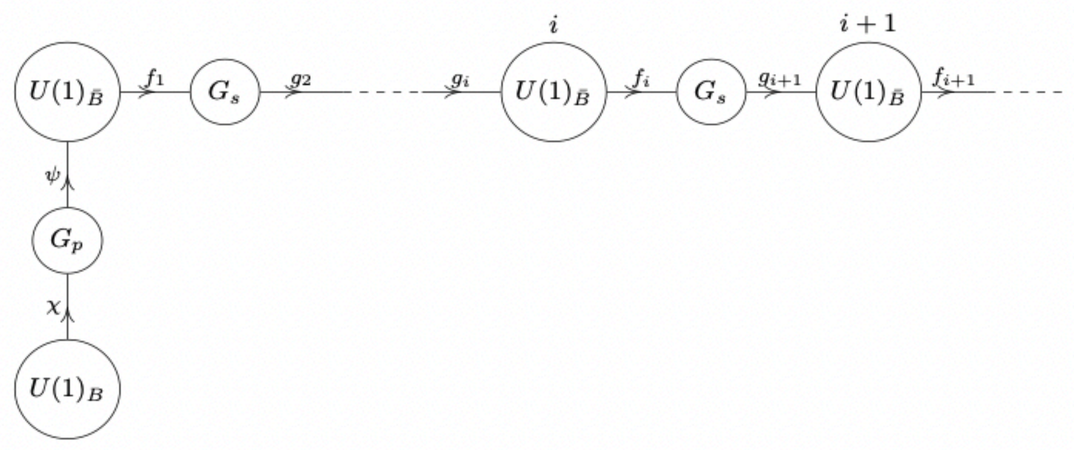

Figure 1. Lattice diagram of the model at short distances compared to the confinement scale $1/\Lambda_s$

At short distances (≪ 1/Λs) the model possess $[U(1)_B \times G_s]^{N+1} \times U(1)_B$symmetry. Whereas, at longer-distances the gauge couplings becomes strong, giving rise to the $[U(1)_B]^{N+1} \times U(1)_B$lattice linked together by the fermion condensates$\langle f_i g_{i+1} \rangle = 4\pi M^3 \Sigma_i$and $\langle \chi \psi \rangle = 4\pi v^3 \Sigma$, as shown in Fig.2, where v ≡ M = Λs/(4π).

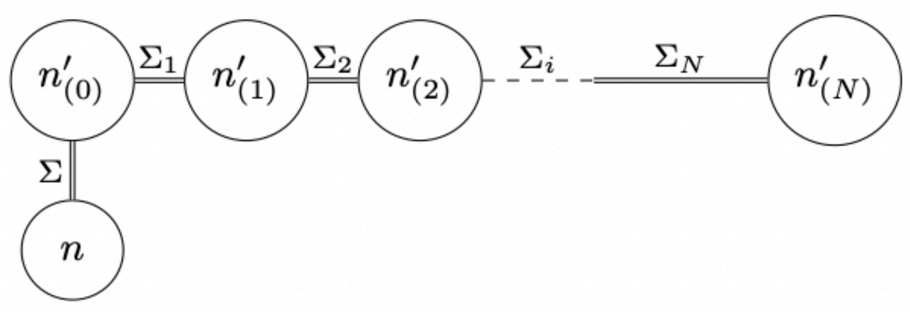

Figure 2. The figure shows the potential for neutron generated after the strong group confines.

For such NP models, it is impossible to express the neutron-antineutron oscillations as quark level effective operator. Instead, we need to study the dynamics at low energies in terms of free SM neutrons and antineutrons using the Lagrangian density

$$\mathcal{L} = i\bar{n}\gamma^\mu \partial_\mu n - \frac{m_n}{2}\left[\bar{n}n + \bar{n^c}n^c\right] - \frac{\epsilon}{2}\left[\bar{n^c}n + \bar{n}\bar{n^c}\right]$$

The operator $\bar{n^c}c$ encompass the new physics contribution that generates ΔB = 2 hadronic transition matrix element

$$\langle \bar{n} | \mathcal{H}_{\Delta B=2} | n \rangle = -\frac{1}{2}\epsilon \; \nu_{\bar{n}}^T C u_n$$

In this condensed linear moose model, we describe the mirror and SM matter fields by two sets of Weyl spinors (n′, n′c) and (n, nc) respectively, located at N+2 sites of the lattice as shown in Fig.2. Low-energy phenomenology of this lattice is governed by the N+1 Σi condensates and Σ. The condensate Σi is charged ($\bar{B} - \bar{B}$) under the $[U(1)^i_{\bar{B}} \times U(1)^{i-1}_{\bar{B}}]$subgroup while Σ is charged $(B - \bar{B})$ under$[U(1)_B \times U(1)_{\bar{B}}]$. The free neutron Lagrangian density appended with the potential, Vn, that generates interactions in the lattice can be written as,

$$\mathcal{L} = i\bar{n}\gamma^\mu \partial_\mu n - \frac{m_n}{2}\left[\bar{n}n + \bar{n^c}n^c\right] + \mathcal{V}_n \; ,$$
$$\mathcal{V}_n = \sum_{i=1}^{N}\left(n'^c_{(i)}\Sigma_i n'_{(i-1)} - m\; n'^c_{(i)} n'_{(i)}\right) - y\;\bar{n}\;\Sigma\; n'_{(0)}$$

Stabilising ⟨Σ⟩ = v and ⟨Σi⟩ = M, the potential can be re-written as

$$\mathcal{V}_n = \sum_{i=1}^{N}\left(M\; n'^c_{(i)} n'_{(i-1)} - m\; n'^c_{(i)} n'_{(i)}\right) - yv\;\bar{n}\;\; n'_{(0)}$$
$$+\,\mathcal{L}_{int}\;,$$

Including an explicit breaking of mirror baryon number localised at the N^{th} node of the the moose potential the new potential can be written as,

$$\mathcal{V}_{\not{B}} = \mathcal{V}_n - \frac{m_M}{2}\bar{n}'_{(N)} n'^c_{(N)}$$

This term can be generated with real representation of fermions transforming under the SO(M) symmetry group. The extra-dimensional interpretation would be to include real fermion mass term localised at the brane. In principle, this term can be located anywhere in the lattice, but a good extra-dimensional description may not be available always. With this, the SM neutron interaction term with mirror neutrons in the Lagrangian, in terms of the rotated fields, is written as

$$\mathcal{V}_{\not{B}} \supset y_{eff} v\; \bar{n}n^0 + m_M\; \bar{n}^0 n^{0\;c}$$

The Lagrangian density of neutron field now becomes

$$\mathcal{L} = i\bar{n}\gamma^\mu \partial_\mu n - \frac{m_n}{2}\left[\bar{n}n + \bar{n^c}n^c\right] - \frac{(y_{eff}v)^2}{m_M}\bar{n^c}n$$
$$+\,\mathcal{L}_{int} + h.c.\;.$$

Where one can see that the neutron oscillation term naturally emerges

$$\frac{\epsilon}{2} = \frac{(y_{eff}v)^2}{m_M}$$
$$= y^2 v^2 \left(\frac{m}{M}\right)^{2N}\frac{1}{m_M}$$

With Yukawa couplings of $\mathcal{O}(1)$, m/M~ 0.1, and m_M~ O(1 GeV), we get $\epsilon \sim 10^{-34}$ GeV for ~ $\mathcal{O}(10)$ gears. Thisresult translates to neutron-antineutron oscillation time period of 108s, which is within the reach of the current and future experiments

We have tested the parameter space with Neutron Star luminosity data and with the current sensitivity the parameter space that can give rise to neutron oscillation is safe.