Unusual Sources of Baryon Number Violation

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Preskill 60'th, March 16 2013

The Good

6. **Cosmology of the Invisible Axion**
John Preskill, Mark B. Wise (Harvard U.), Frank Wilczek (Santa Barbara, KITP). Sep 1982. 14 pp.
Published in **Phys.Lett. B120 (1983) 127-132**

The Bad

3. **Wormholes In Space-time And Theta (qcd)**
John Preskill, Sandip P. Trivedi, Mark B. Wise (Caltech). Mar 3, 1989. 13 pp.
Published in **Phys.Lett. B223 (1989) 26**

The Ugly

5. **Neutrino Masses And Family Symmetry**
Benjamin Grinstein, John Preskill, Mark B. Wise (Caltech). May 1985. 13 pp.
Published in **Phys.Lett. B159 (1985) 57**
CALT-68-1266

This Talk

. **Simplified models with baryon number violation but no proton decay**
Jonathan M. Arnold, Bartosz Fornal, Mark B. Wise. Dec 2012. 7 pp.
CALT-68-2898
e-Print: **arXiv:1212.4556 [hep-ph]** | PDF

Introduction

Standard Model (SM) has automatic symmetry B-L of renormalizable lagrangian. B is also an automatic symmetry classically. But its anomalous. Not important at T=0 but important at High T.

$$B = \frac{28}{79}(B-L)$$

B violated at dimension 6. eg. $\frac{u_R u_R d_R e_R}{\Lambda^2}$

Mean lifetime for mode $p \to e^+\pi^0$ greater than

$$8.2 \times 10^{33} \text{ years}$$

Scale greater than about 10^{16}GeV

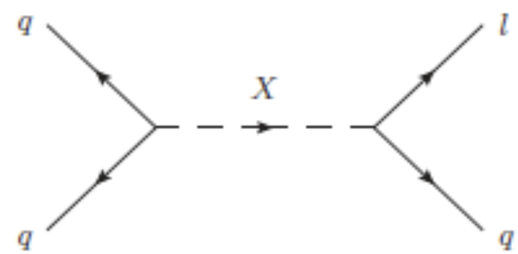
Simplest Models With Baryon number violation but no proton decay: Method

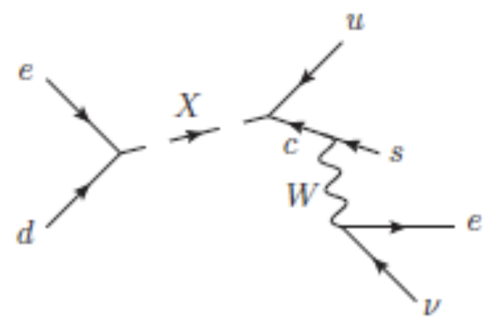
- Proton decay violates baryon number by one unit and lepton number by and odd number of units.
- Interaction violates baryon number by one unit but conserves lepton number or violates or violates baryon number by two units then no proton decay, for example.
- Can happen in supersymmetric models since there is a renormalizable operator that violates baryon number but not lepton number.
- But still could get baryon number violating process like: $n - \bar{n}$ oscillations or $p + p \to K^+ K^+$

- Simplest (least number of fields) have two new fields $X_{1,2}$ that couple to bilinears of quark/lepton fields:

operator	$SU(3) \times SU(2) \times U(1)$ rep. of X	B	L
XQQ, Xud	$(\bar{6}, 1, -1/3)$, $(3, 1, -1/3)_{\rm PD}$	$-2/3$	0
XQQ	$(\bar{6}, 3, -1/3)$, $(3, 3, -1/3)_{\rm PD}$	$-2/3$	0
Xdd	$(3, 1, 2/3)$, $(\bar{6}, 1, 2/3)$	$-2/3$	0
Xuu	$(\bar{6}, 1, -4/3)$, $(3, 1, -4/3)_{\rm PD}$	$-2/3$	0
$X\bar{Q}\bar{L}$	$(3, 1, -1/3)_{\rm PD}$, $(3, 3, -1/3)_{\rm PD}$	$1/3$	1
$X\bar{u}\bar{e}$	$(3, 1, -1/3)_{\rm PD}$	$1/3$	1
$X\bar{d}\bar{e}$	$(3, 1, -4/3)_{\rm PD}$	$1/3$	1
$X\bar{Q}e, XL\bar{u}$	$(3, 2, 7/6)$	$1/3$	-1
$X\bar{L}d$	$(\bar{3}, 2, -1/6)_{\rm PD}$	$-1/3$	1
XLL	$(1, 1, 1)$, $(1, 3, 1)$	0	-2
Xee	$(1, 1, 2)$	0	-2

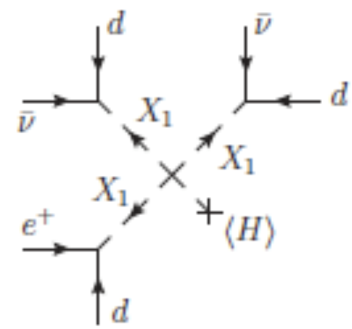
- Quantum numbers (SU(3),SU(2), U(1)) that tree level nucleon decay eliminates: (3,1,-1/3), (3,3,-1/3),(3,1,-4/3).
- Actually (3,1,-4/3) needs extra W boson because of antisymmetry



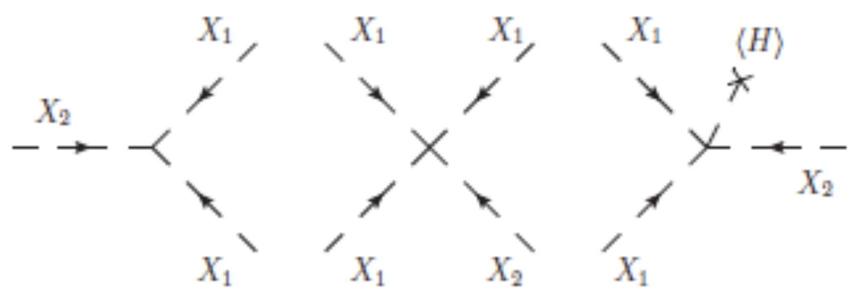


Eliminate representation $(\bar{3}, 2, -1/6)$

Gives the decay $p \to \pi^+\pi^+ e\nu\nu$



Write most general interactions consistent with
The gauge symmetries. Violate baryon number from



The 9 Models

- Model 1: $X_1 = (\bar{6}, 1, -1/3), \quad X_2 = (\bar{6}, 1, 2/3)$
- Model 2: $X_1 = (\bar{6}, 3, -1/3), \quad X_2 = (\bar{6}, 1, 2/3)$
- Model 3: $X_1 = (\bar{6}, 1, 2/3), \quad X_2 = (\bar{6}, 1, -4/3)$
- Model 4: $X_1 = (3, 1, 2/3), \quad X_2 = (\bar{6}, 1, -4/3)$
- Model 5: $X_1 = (\bar{6}, 1, -1/3), \quad X_2 = (1, 1, 1)$
- Etc.

List not that informative. Lets look briefly
Into phenomelology of model 1

Model 1

Fields: $\mathrm{X}_1 = (\bar{6}, 1, -1/3), \;\; X_2 = (\bar{6}, 1, 2/3)$

Lagrangian:

$$\begin{aligned} \mathcal{L} \;\; = \;\; & - g_1^{ab} X_1^{\alpha\beta} \left(Q_{L\alpha}^a \epsilon\, Q_{L\beta}^b \right) - g_2^{ab} X_2^{\alpha\beta} (d_{R\alpha}^a d_{R\beta}^b) \\ & - g_1'^{ab} X_1^{\alpha\beta} (u_{R\alpha}^a d_{R\beta}^b) + \lambda X_1^{\alpha\alpha'} X_1^{\beta\beta'} X_2^{\gamma\gamma'} \epsilon_{\alpha\beta\gamma} \epsilon_{\alpha'\beta'\gamma'} \end{aligned} \qquad (1)$$

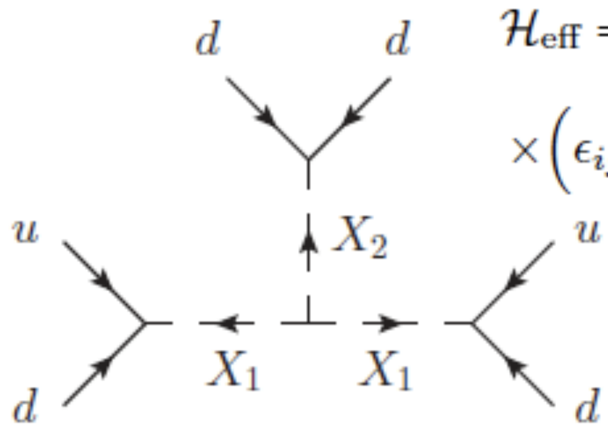
Coupling λ has dimensions of mass.
Baryon number violation because of λ
Coupling g_1 is antisymmetric on flavor indices,
g_1' and g_2 are symmetric on flavor indices

Neutron Anti-Neutron Oscillations

Neutron anti-neutron oscillation time $\tau_{n\bar{n}} = 1/\Delta m$

$$\Delta m = \langle \bar{n} | \mathcal{H}_{eff} | n \rangle \qquad P_{n\rightarrow\bar{n}} = sin^2(t/\tau_{n\bar{n}})$$

Experiment SuperK limit, $\Delta m < 2 \times 10^{-33}\mathrm{GeV}$



$$\mathcal{H}_{\rm eff} = -\frac{(g_1'^{11})^2 g_2^{11}\lambda}{4M_1^4 M_2^2} d^{\dot\alpha}_{Ri} d^{\dot\beta}_{Ri'} u^{\dot\gamma}_{Rj} d^{\dot\delta}_{Rj'} u^{\dot\lambda}_{Rk} d^{\dot\chi}_{Rk'} \epsilon_{\dot\alpha\dot\beta}\epsilon_{\dot\gamma\dot\delta}\epsilon_{\dot\lambda\dot\chi}$$
$$\times\left(\epsilon_{ijk}\epsilon_{i'j'k'} + \epsilon_{i'jk}\epsilon_{ij'k'} + \epsilon_{ij'k}\epsilon_{i'jk'} + \epsilon_{ijk'}\epsilon_{i'j'k}\right) + \mathrm{h.c.}$$

Calculate matrix element using vacuum insertion approximation. One matrix element needed between neutron three quark fields and vacuum.

Expressed in terms of one dimensionful parameter β that has been measured using lattice QCD $\beta \simeq 0.01 \mathrm{GeV}^3$

$$|\Delta m| = 2\lambda\beta^2 \frac{|(g_1'^{11})^2 g_2^{11}|}{3M_1^4 M_2^2}$$

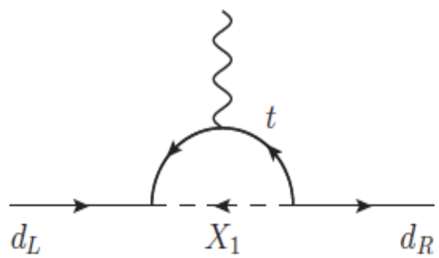
All dimensionful parameters equal to M Yukawa coupling constants equal to unity then $M > 500 \mathrm{TeV}$

Another extreme $M_1 = 5 \mathrm{TeV}$ above LHC limits.

Then with $\lambda = M_2$ find $M_2 > 5 \times 10^{13} \mathrm{GeV}$

Flavor Physics

- Get a contribution to quark electric dipole moments not suppressed by quark mass



$$|d_d| \simeq \frac{m_t}{6\pi^2 M_1^2} \log\left(\frac{M_1^2}{m_t^2}\right) \left|\text{Im}[g_1^{31}({g'}_1^{31})^*]\right| e\text{cm}$$

- Experiment: $d_n^{\text{exp}} < 2.9 \times 10^{-26} e\text{cm}$

$M_1 = 500\text{TeV}$ then $\left|\text{Im}[g_1^{31}({g'}_1^{31})^*]\right| \lesssim 6 \times 10^{-3}$

•Another strong constraint from $K-\bar{K}$ mixing that arises at tree level from the exchange of X_2

$$\mathcal{H}_{\rm eff} = \frac{g_2^{22}\left(g_2^{11}\right)^*}{M_2^2}\left(s_{R\alpha}s_{R\beta}\right)\left(d_R^{*\alpha}s_R^{*\beta}\right)$$
$$\rightarrow \frac{g_2^{22}\left(g_2^{11}\right)^*}{2M_2^2}\left(\bar{d}_R^{\alpha}\gamma^{\mu}s_{R\alpha}\right)\left(\bar{d}_R^{\alpha}\gamma_{\mu}s_{R\alpha}\right),$$

Implies that:

$$\left|\mathrm{Re}\left[g_2^{22}\left(g_2^{11}\right)^*\right]\right| < 1.8\times 10^{-6}\left(\frac{M_2}{1\ \mathrm{TeV}}\right)^2,$$
$$\left|\mathrm{Im}\left[g_2^{22}\left(g_2^{11}\right)^*\right]\right| < 6.8\times 10^{-9}\left(\frac{M_2}{1\ \mathrm{TeV}}\right)^2.$$

Generating a Baryon Asymmetry

- Use same method introduced for grand unified theories. Net baryon number per $X_2 X_2$ pair is $2(r - \bar{r})$

Decay	Br	B_f
$X_2 \to \overline{X}_1 \overline{X}_1$	r	$4/3$
$X_2 \to \bar{d}_R \bar{d}_R$	$1 - r$	$-2/3$
$\overline{X}_2 \to X_1 X_1$	$\bar{r}$	$-4/3$
$\overline{X}_2 \to d_R d_R$	$1 - \bar{r}$	$2/3$