Baryon and Lepton Number Overview

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The standard model has proved extremely successful. As far as particle physics experiments are concerned the only evidence for physics beyond the standard model comes from neutrino oscillations. However, a minor modification involves adding the right-handed neutrinos, which is quite natural given the apparent lepton-quark symmetry. The neutrinos can then get a Dirac mass via Higgs couplings and it is natural to expect flavor mixing. I will refer to this as the "standard model of neutrino mass".

The problem, of course, is that the mass of the most massive neutrino is more than a million times smaller than the mass of the lightest of the other particles, the electron. Of course, the electron mass is 300,000 times smaller than the top mass and we have learned to live with that. But now we find a ratio of the top mass to neutrino mass of order 10^{12}, a number suggestive of the ratio of the GUT scale to the electroweak scale. So perhaps this is a clue to physics at a high mass scale.

The phenomenology of physics beyond the standard model can be described by using an "effective theory" in which terms of dimension d greater than 4 invariant under the standard model symmetry are added to the standard model interaction. These are proportional to the inverse (d-4) power of some large mass. Such terms, of course, are to be used only in lowest order perturbation theory. A list of such terms that violate baryon and lepton number but conserve the standard model SU(3) x SU(2) x U(1) has been given by Weinberg [1] and others. An early example is Fermi's weak interaction which has dimension 6 and served very well for 40 years with the addition of the requirement that all fermion fields are left-handed chiral fields.

Neutrino masses are obtained by adding a term of dimension 5 of the form

$$f_{ij}\nu_i\nu_i\varphi\varphi / M_1 \tag{1}$$

which has a $\Delta L = 2$ coupling to the Higgs field φ. The resulting neutrino Majorana mass matrix is given by

$$M_\nu = f_{ij}v^2 / M_1 \tag{2}$$

If f_{ij} were of order unity the mass M_1 would be of order 10^{14} Gev. In the see-saw model [2], inspired by SO(10), M_1 is the mass scale of the right-handed neutrinos. It is also possible in SO(10) that the coupling in (1) is mediated by a triplet Higgs in the s-channel so that M_1 is the triplet mass [3]. Still more complicated possibilities involve charged scalar bosons and multi-loop diagrams. (4).

It is of great interest to search for explicit $\Delta L = 2$ processes. Of these the most promising is neutrinoless nuclear double beta-decay: $Z \to Z + 2 + e^- + e^-$.

Considering this as a process directly due to new physics we would write an effective interaction of the form

$$\overline{u}d\overline{u}d\overline{e}\overline{e} \tag{3}$$

of dimension 9 proportional to M_2^{-5}. However it is expected to occur via a virtual Majorana neutrino in which case it is proportional to $v^2 / M_1 M_w^4 < Q^2 > \sim 1/ M_1 M_w^2 < Q^2 >$ where $< Q^2 >$ comes from the neutrino propagator and has a value of order $10^3 Mev^2$ determined by nuclear physics. Thus there is only one power of a large mass, M_1 in the

M^5 denominator. However it is possible that the neutrino mass contribution to double beta-decay is zero because it is proportional to M_{ee}, a component of the mass matrix which corresponds to a linear function of neutrino masses. For the tribimaximal mixing, which fits present data, M_{ee} vanishes if $m_2 = 2m_1$ and the states 2 and 1 have opposite CP eigenvalues.

In any case, it is of great interest to know whether other new physics contributes significantly. Assuming this new contribution arises from diagrams with new heavy particles of mass of order M_2, then M_2 must be no larger than 1 Tev if this is to make a detectable effect on double beta-decay.

There are a number of reasons to consider baryon number violation:

(1) There is the suggestion originally due to SAKHAROV that CP violation combined with a ΔB interaction could explain the baryon asymmetry of the universe.

(2) Many grand unified theories (GUT) predicted a proton decay rate that could be detectable. This motivated the construction of large detectors like 1MB, Kamiokande, and SUPERK that detected Supernova 87 a and neutrino oscillations. However there was no proton decay.

(3) B-L is an important symmetry. Thus if you believe in ΔL perhaps there is also ΔB. In particular in the standard model—in the electro-weak phase transition there is a possibility of a ΔB, ΔL transition that conserves B-L, an essential component of leptogenesis theories.

Effective interactions giving proton decay are of dimension 6 such as

$$(\text{u u d e })/M_3^2$$

These necessarily conserve B-L and so yield decay like $p \to \pi^0 e^+$.

If neutrino mass is due to $\Delta L = 2$ then possibly there exists $\Delta B = 2$, which could lead to neutron-antineutron oscillations. The analogue of (1) would be $nn\varphi\varphi$, which well above the QCD scale becomes of the form

$$(qqqqqq\varphi\varphi)/M_4^7$$

which has dimension 11 rather than 5. Thus there is no simple relation between $\Delta L = 2$ and $\Delta B = 2$. However, as in the discussion of double beta-decay, the factor labeled M_4^7 may be the product of some ordinary masses times one or two large masses responsible for $\Delta B = 2$. I am sure some such models will be discussed in later talks.

In conclusion, the search for baryon and lepton number non-conservation represents an important probe of physics beyond the standard model and particularly new physics at a very high mass scale.

1. S. Weinberg, Phys. Rev. Lett 43, 1566 (1979)

2. M. Gell-Mann, P. Ramond and R. Slanosky, private communication at Aspen (1977)

3. R. N. Mohapatra and G. Senjanovic, Phys. Rev. D23, 165 (1981) and references therein

4. D. Chang and A. Zee hep-ph/9912380. For a detailed review see A. Abada et al hep-ph 0707.4058.