"BEYOND THE STANDARD MODEL" - GRAND UNIFICATION SUBGROUP

Introductory Remarks

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Among the most exciting prospects for new physics discoveries during the next few years are those pertaining to grand unification theories (GUT's), in which (anti)quarks and (anti)leptons are placed together in (irreducible) representations of a simple gauge group. Examples of such groups include SU(5) and SO(10). These local symmetries are only good at energies >> $\sim 10^{14}$ GeV and are spontaneously broken below this mass scale. By construction, grand unified theories involve transitions between q and q^c, q and ℓ^c and optionally, also ℓ and ℓ^c, where q and ℓ denote generic quarks and leptons, respectively. These theories thus naturally violate baryon and lepton number. In particular, the proton and bound neutron are predicted to decay, via fundamental transitions such as $u + u \to d^c + e^c$ and $u + d \to u^c + e^c$ or $d^c + \nu_e^c$. If one makes the simplifying assumption that there are no intermediate mass scales at which new physics occurs between $\sim 10^2$ GeV and the grand unification mass, then one can obtain a number of predictions, including one for the lifetime of the proton or bound neutron. The result is tantalizingly close to the present experimental lower bound, providing strong motivation for intensive experimental searches for nucleon decay. The type of facility which is appropriate for these searches is a detector in a deep mine or deep underground national laboratory (or a deep automobile tunnel, of the kind available in Europe but not in the U.S.). The physics goals and prospects for U. S. experiments on nucleon decay are discussed in the report entitled "Prospects for Future Experiments to Search for Nucleon Decay" by D. Ayres et al. in these proceedings.

A second prediction of grand unified theories is the value of $\sin^2\theta_W = g'^2/(g^2 + g'^2)$, where g and g' are the gauge couplings for the SU(2) and U(1) factor groups in the standard SU(3) × SU(2) × U(1) model. Starting with the value $\sin^2\theta_W = 3/8$ at the unification mass scale, and again assuming the absence of intermediate mass scales and new physics, one can calculate the "low" -energy value of $\sin^2\theta_W$ which is appropriate to compare with experimental data derived from neutrino reactions and polarized electron scattering. As noted in the report on nucleon decay in these proceedings, the agreement with the minimal GUT is quite good. The prospects for more precise measurements of $\sin^2\theta_W$ using Z production in hadron-hadron and e^+e^- colliders, and using neutrino reactions, are discussed in the corresponding sections of the proceedings.

A third general feature of grand unified theories is the existence of magnetic monopoles (which also transform nontrivially under color SU(3)). These "appear" when the original simple gauge group, G, breaks to a group of the form H × U(1). In the simplest scenario, G = SU(5), which breaks to SU(3) × SU(2) × U(1) at $M_{GU} \sim 10^{16}$ GeV. The monopoles are predicted to have masses of order $\alpha^{-1}M_{GU} \sim 10^{16}$ GeV. Several groups are designing magnetic monopole detectors, stimulated partially by the recently reported observation of a monopole by B. Cabrera. As with proton decay, these detectors obviously fall under the category of non-accelerator facilities. A discussion of the present status of, and future prospects for, monopole searches is given in the report by D. Ayres et al. in these proceedings.

In addition to these natural predictions, there are several other phenomena which may occur in grand unified theories, including $n - \bar{n}$ transitions and the resultant matter instability, and neutrino masses, of Dirac and/or Majorana type, together with the associated lepton mixing. Neither of these two possible phenomena is a generic or necessary prediction of grand unified theories, in contrast to proton decay and magnetic monopoles. Indeed, both of them can occur in the absence of grand unification. Thus, the observation of either of these effects would not, by itself, constitute evidence for GUT's, although it would be extremely interesting in its own right. The $n - \bar{n}$ transition violates baryon number, B, by two units and, in addition, violates (B - L) (where L denotes total lepton number), a quantum number that is exactly conserved in many GUT's, including minimal SU(5). Further, such transitions can occur take place at a significant rate only if the "desert" hypothesis is false, i.e., there are new particles and associated new physics at a mass intermediate between 10^2 and 10^{14} GeV. Searches for $n - \bar{n}$ transitions can be carried out in fine-grained nucleon decay detectors and in propagation experiments at reactors. For a report on this subject, see R. Shrock, "$n - \bar{n}$ Oscillations - Theory and Experiment," in these proceedings. The lepton mixing which naturally occurs concomitantly with neutrino masses violates lepton family number. Neutrino masses violate total lepton number if they are of Majorana type, but not if they are of Dirac type. Tests for such masses and mixing can be performed using nuclear β decay, and π, K, μ, and τ decays at meson laboratories such as SIN, KEK, TRIUMF, and LAMPF, and e^+e^- storage rings, such as SPEAR, respectively. Neutrino oscillations can be tested for in deep mine experiments meson laboratories, and both 30 GeV and 400 GeV proton accelerators, operating in the fixed target mode. Indeed, these various facilities complement each other in a very useful manner. The search for neutrino masses and mixing thus provides motivation for high resolution, high statistics nuclear β decay experiments, further direct decay experiments, at meson laboratories and medium energy (4 - 10 GeV), high intensity e^+e^- colliders, and new neutrino oscillation experiments at all appropriate facilities. This subject is discussed in the reports by D. Caldwell, R. Lanou and R. Shrock on neutrino masses and mixing in these proceedings.

In summary, it seems clear that some of the most interesting new experimental physics during the coming years will be concerned with testing grand unified theories and searching for the related phenomena of $n - \bar{n}$ oscillations and neutrino masses and mixing.