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Some Thoughts on Searches for Proton Decay

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SOME THOUGHTS ON SEARCHES FOR PROTON DECAY*

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At the Conference I summarized the results of searches for proton decay as reported by various groups at the XIXth Rencontre de Moriond[1] which took place a week earlier. Since the detailed talks given there will be published in the near future, there seems to be no point in repeating the evidence in this report. Instead, I would like to put down some tentative thoughts which might be worth keeping in mind in further searches for proton decay.

The minimal SU(5) theory appears to be contradicted by the experiment of Bionta et XXVIII al.[2] who find a lifetime longer than predicted by this theory. However, A.S. Goldhaber, T. Goldman, and S. Nussinov have recently pointed out that final state interaction due to strong meson field couplings may suppress proton decay by one or two orders of magnitude, which may yield a lifetime approaching the present experimental limit (see 5th Workshop on Grand Unification, and Physics Letters, to be

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published). We shall have to see whether the gap between experiment and theory will increase or decrease with time, as both are refined.

The Kolar Goldfields, Nusex, IMB, Kamiokande and HPW experiments all find contained events which include proton decay candidates. Improved detectors are being prepared at the Kolar Goldfields and at Soudan (Minnesota); a fine grained detector being installed at Fréjus should approach $\sim$ 1 kton by the end of the year. The IMB water Cherenkov detector is being upgraded to collect a bigger fraction of the light in order to improve particle identification and energy determination. But even with the good light collection already achieved by Kamiokande, there are still ambiguities left in the assignment of decay modes to candidates, as reported at the XIXth Rencontre de Moriond[1] by Y. Totsuka.

To establish proton decay, if it exists, we have to demonstrate reproducibility, which implies large detectors and long observation times. This may permit the background events from atmospheric neutrinos to become ultimately "self-calibrated", provided that in the mass region of interest, above and below the proton mass, background events with topologies similar to those expected from proton decay can be assumed to vary continuously in intensity.

It is useful to imagine what we could achieve if we were able to build detectors which approach an "ideal" detector, defined as one which allows one to determine, without ambiguity, the different kinds of decay particle including their charges and energies. We shall make the assumption that for all proton decays in which only one fermion is emitted there exists a selection rule which forces the fermion to be either a lepton or an anti-lepton. The charged-current interaction of atmospheric neutrinos will give an unavoidable, "intrinsic" background when the neutrinos produce leptons of the same electric charge as is found in proton decay. Thus, either neutrinos ($\overleftarrow{\nu}$) or antineutrinos ($\overrightarrow{\nu}$), but not both, will be responsible for this intrinsic background. For a proton decay in which an uncharged lepton is emitted, neutral-current interactions of both neutrinos and anti-neutrinos will give an intrinsic background, though with a cross-section smaller than for the charged-current interaction. A special case would be the decay modes $p \rightarrow \overset{\leftrightarrow}{\nu} K^+$ and $n \rightarrow \overset{\leftrightarrow}{\nu} K^o$ for which there is no intrinsic background because of the absence of strangeness changing neutral currents (GIM mechanism). With the new and improved detectors now in preparation, it should be possible to identify characteristic kaon decays, though, at finite resolution, some non-intrinsic neutrino background, which could again be "self-calibrated", will have to be taken into account.

Before we can convince ourselves that the proton actually decays (if it does so in the "window of vulnerability" accessible to experiments in the available detectors), we must demand, besides reproducibility, some of the fairly obvious consistency checks, which I discussed at the XIXth Rencontre de Moriond[1]. Thus, e.g., if candidates interpreted as $p \rightarrow \mu^+ K^o$ with $K^o \rightarrow 2\pi^o$ are observed, then there should be about twice as many candidates $p \rightarrow \mu^+ K^o$ with $K^o \rightarrow \pi^+\pi^-$. Also, if proton decay candidates are found with a momentum imbalance ascribed to the Fermi momentum of protons bound in nuclei, then one can predict, after nuclear corrections, how many similar events should originate from the unbound protons in H_2O where momenta should be balanced.

More than a dozen candidates of varying "quality" have by now been reported from the experiments in progress. For no single case can we exclude the possibility that it is a neutrino induced background event. But, if we keep an open mind, and for the sake of argument assume that many of these events are indeed due to proton decays, rather than produced by atmospheric neutrinos, it would seem about time that decays from free hydrogen should be observed, i.e., events in which momenta appear balanced.

The many dedicated experimental searches for proton decay begun in the last few years were catalyzed by theoretical predictions. But a catalyst should not be contained in the final result! Is that indeed the case here? In the interpretation of candidates one usually tacitly assumes that one particle is an anti-lepton (e^+, μ^+, $\bar{\nu}$), as expected from SU(5) and related theories where B-L is conserved, rather than a lepton (e^-, μ^-, ν), an alternative which an open-minded, phenomenological approach should at least consider. The anti-lepton is usually assumed to be accompanied by a meson, which may show further decay. But since the existing detectors are rather insensitive to the sign of charged leptons, and mesons can suffer charge exchange in the nucleus, these interpretations are often not unique.

Unless there are special selection rules one would expect from phase space considerations that two-body decays predominate.[3] If leptons rather than anti-leptons were emitted, then two-body events could arise in both proton and neutron decay when either a neutrino or anti-neutrino is emitted, but, because of charge conservation, only in neutron decay when a charged lepton is emitted (e.g., $n \rightarrow e^-\pi^+$). It is intriguing that detectors which contain iron as source material, where the ratio of neutrons to protons (n/p) is nearly 45% larger than in water, appear to yield more candidates per ton-year than do those which contain water, though better statistics are needed before this can be considered significant.[4] If one wants to pursue the uncertain hints of n/p dependence (or of some unforeseen nuclear structure effects) one might alternate layers of materials with large n/p—e.g., in an extreme case, bismuth (126/83)—with materials with small n/p, e.g., polyethylene $(CH_2)_n$(6/8), thus changing n/p between layers by about a factor of two, while also supplying a source of unbound protons. Such an alternation of high Z and low Z layers would also yield—as a bonus—some information on the charges of muons and pions. In bismuth stopping μ^+ and π^+ decay, while μ^- and π^- are absorbed, whereas in polyethylene essentially only π^- is absorbed.

The next few years should show whether some of the candidates for proton decay will pass reproducibility and consistency criteria, with either lepton or anti-lepton emission.

References and Footnotes

1. Talks by M. Goldhaber, E. Shumard, J. van der Velde, Y. Tosuka and S. Ragazzi at the XIXth Rencontre de Moriond, LaPlagne, France, March 1984 (to be published).
2. R.M. Bionta, G. Blewitt, C.B. Bratton, B.G. Coretz, S. Errede, G.W. Foster, W. Gajewski, M. Goldhaber, J. Greenberg, T.J. Haines, T.W. Jones, D. Kielczewska, W.R. Kropp, J.G. Learned, E. Lehmann, J.M. LoSecco, P.V. Ramana Murthy, H.S. Park, F. Reines, J. Schultz, E. Shumard, D. Sinclair, D.W. Smith, H.W. Sobel, J.L. Stone, L.R. Sulak, R. Svoboda, J.C. van der Velde and C. Wuest, Phys. Rev. Lett. 51, 27 (1983), and later work.
3. In the decay of another fermion, the τ, which is nearly twice as heavy as the proton, and thus has a considerably larger phase space available for multi-particle decay, it is found that about half or more of the semileptonic decays are two-body decays (see Particle Data Tables).
4. One should however remember that the background produced by atmospheric neutrinos also depends on the ratio n/p.