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The search for proton decay and other rare phenomena

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We have obtained the first results with a large water Cherenkov counter located in a salt mine in Ohio. (Bionta *et al.* 1983. Submitted to *Phys. Rev. Lett.*) The partial lifetime for the decay $p \rightarrow e^{+}\pi^{0}$ is found to be longer than the value calculated from the minimal SU(5) theory, with the best presently available estimates for the parameters needed. The detector is sensitive to some other potential decay modes, as well as to some rare phenomena that have been discussed in recent years. The characteristics of the penetrating cosmic ray muons and atmospheric neutrino interactions observed are compatible with expectations.

Astronomers are fond of saying, 'the absence of evidence is not the evidence of absence'. Nevertheless, it was believed for a long time that protons are absolutely stable. Since 1954, however, proton stability has been subjected directly to fairly sensitive empirical tests (Reines *et al.* 1954).

Sometimes I am asked how my interest in proton decay started. As I remember it, it began about 30 years ago when the theory of continuous creation advocated by Bondi, Gold and Hoyle was much discussed. If protons could be created out of nothing, might they not also have a chance to disappear? If such a disappearance took place, it might show up by leaving a nuclear excitation. This could be detected, for instance, in thorium by what would look like spontaneous fission. But once one considers disappearance of protons, a more conservative approach would be to ask whether protons could decay into other particles conserving energy, momentum, electric charge, and angular momentum. At that time, Reines and Cowan had a large neutrino detector, a scintillation counter, and it seemed natural to use it to search for charged particles which might arise from proton decay. Thus, the first proton decay experiments and many thereafter were parasitic to a neutrino search. Nowadays, this has often been reversed, with dedicated proton decay detectors also being used as neutrino detectors; these experiments are now symbiotic, rather than parasitic.

Over the years, the limits on proton lifetime were increased by various methods to around 10^{30} years. Then, starting in 1973 with suggestions by Pati and Salam, by Georgi and Glashow, and by Georgi, Quinn and Weinberg, and by others, the idea of grand unification was shown to lead to the prediction that quarks could change into leptons, making protons unstable. In particular, the so-called minimal SU(5) theory, and equivalently some higher groups, for example, SO(10) and SU(16), as emphasized especially by Weinberg and Pati, make a fairly well defined prediction for the proton lifetime, not much longer than the previous experimental limit. It seemed therefore possible to test this prediction with reasonably sized detectors.

Many such experiments are now in progress or being prepared. The Kolar gold field experiment found three contained events, considered as candidates for proton decay, and the Mont Blanc experiment has reported one candidate. The Irvine–Michigan–Brookhaven experiment (Bionta *et al.* 1983) has recently reported its first results:

> 'Observations were made 1570 mwe underground with an 8000 metric ton water Cherenkov detector. During a live-time of 80 days no events consistent with the decay $p \rightarrow e^+\pi^0$ were found in a fiducial mass of 3300 metric tons. We conclude that the limit on the lifetime for bound plus free protons divided by the $e^+\pi^0$ branching ratio is $\tau/B > 6.5 \times 10^{31}$ years; for free protons our limit is $\tau/B > 1.9 \times 10^{31}$ years (90 % confidence). Observed cosmic ray muons and neutrinos are compatible with expectations.'

While we concentrated first on the $e^+\pi^0$ decay mode, we are also sensitive to most other potential two-body decay modes, as well as to some multi-body modes. By Monte Carlo simulation, the sensitivity of our detector for each decay mode, as well as the neutrino induced background of similar appearance, can be estimated. In physics, reproducibility is vital. With rare events we must be very careful: Nature might be giving us a Rorschach test! We can give limits for the $K^0\mu^+$ decay mode ($> 1.4 \times 10^{31}$ a) as well as for n–$\bar{n}$ oscillations in oxygen ($> 10^{31}$ a). According to Dover *et al.* (1983), this corresponds to a free n–$\bar{n}$ oscillation time of greater than 5×10^7 s.

We have also carried out a search (Errede *et al.* 1983) for magnetic monopoles 'catalyzing' nucleon decay as suggested by Rubakov and Callan.

> 'No positive evidence for such a process has been found during 100 days of detector live-time. For an average cross section of $H_2O > 10$ mb† and velocities $10^{-4} < \beta_m < 10^{-1}$, we find a limit for the monopole flux $< 7.2 \times 10^{-15}\,\mathrm{cm^{-2}\,sr^{-1}\,s^{-1}}$.'

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† 1b = 10^{-28} m^2.