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E-mail to Fred Gilman: gilman@cmuhep2.phys.cmu.edu
Subj: Planning for the Future of U.S. High-Energy Physics

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Dear Professor Gilman:

We would like to attract the attention of HEPAP to the situation with regard to an experimental search for baryon number non-conservation. As you know, nucleon instability (a) is required for the explanation of baryon asymmetry of the universe (BAU) and (b) is a direct consequence of the concept of Unification of particles and forces. So far, experimental searches for nucleon decay have been pursued mainly through the nucleon decay modes where (B–L) is conserved, such as $p \rightarrow e^{+} + \pi^{0}, p \rightarrow \overline{\nu} + K^{+}, p \rightarrow \mu^{+} + K^{0}$, etc. These decay modes were predicted and expected to be dominant in SU(5) and SUSY-extended models. As a result of experimental efforts of the IMB, Fréjus, Kamiokande, Soudan-2 and, particularly, Super-Kamiokande collaborations, impressive limits on nucleon lifetime have been established, ruling out the original SU(5) and one-step-breaking SO(10) models. Although it is important to continue to search for the nucleon instability in the traditional way with the next generation of large-mass detectors, we believe that it is also essential to explore alternative processes where (B–L) might not be conserved, and in particular the neutron to antineutron transition $n \rightarrow \overline{n}$ with $\Delta$(B–L)= –2.

As was pointed out by M. Gell-Mann and A. Pais in 1955, the only conservation law of nature that would forbid the $n \rightarrow \overline{n}$ transition is the conservation of *baryon number*. In 1970, $n \rightarrow \overline{n}$ transitions were considered by V. Kuzmin as a possible explanation of BAU. In the 1980s, it was suggested by S. Glashow in the context of SU(5) models and independently by R. Marshak, R. Mohapatra in the context of left-right symmetric models that the $n \rightarrow \overline{n}$ transition could lead to theoretical unification schemes complementary or alternative to those exploiting the (B–L) conserving proton decay mechanism. In particular, R. Marshak and R. Mohapatra pointed out that there is an intimate connection between a nonvanishing Majorana mass for neutrinos and possibility of the $\Delta$(B–L) = –2 $n \rightarrow \overline{n}$ transition. The recent discovery of neutrino mass therefore strengthens the case for a new dedicated search for $n \rightarrow \overline{n}$ oscillation.

In nucleon decay processes (with $\Delta$B=–1) the non-conservation of (B–L) implies the existence of transitions of the type $N \rightarrow l + X$ (the conservation of (B–L) corresponds to $N \rightarrow \bar{l} + X$ transitions). If (B–L) can be violated by two units, it is natural to assume, as also follows from the Unification models, that processes with $|\Delta L|$=2 and $|\Delta B|$=2 are also the components of physics of the energy scale where (B–L) is violated. Examples of these are heavy Majorana neutrinos with $|\Delta L|$=2 transitions of $\nu \leftrightarrow \overline{\nu}$ and the transitions of $n \rightarrow \overline{n}$ with $\Delta$B=–2. Thus, the explanation of the masses of neutrinos through the see-saw mechanism suggested by M. Gell-Mann, P. Ramond, R. Slansky, T. Yanagida, R. Mohapatra and G. Senjanovic in 1979 can be linked to the (B–L) and B non-conservation.

In 1985, V. Kuzmin, V. Rubakov, M. Shaposhnikov and others realized that baryon asymmetry of the universe, if created by (B–L) conserving processes at Unification scale, will be essentially destroyed by non-perturbative, electro-weak *sphaleron* mechanism. Although the theoretical efforts are being made to understand how BAU can be generated by (B–L) conserving processes at temperatures below the unification scale, it would be natural to assume that *(B–L) non-conservation* takes place at the energies above the electro-weak scale. In this sense, the discovery of (B–L) conserving proton decay, like $p \to e^+ + \pi^0$, is not advancing our understanding of BAU.

The possibility of the existence of $n \to \bar{n}$ transitions has been explored experimentally in intranuclear transitions (Fréjus, Kamiokande, IMB) up to a lifetime limits of > $6.5 \cdot 10^{+31}$ years approaching those for proton decay. Moreover, similar limits were obtained by Heidelberg-ILL-Padova-Pavia collaboration in a free-neutron vacuum-oscillation search experiment at the ILL reactor in Grenoble although the vacuum transition time limit was set there only to be $\geq 10^{+8}$ seconds. This clearly demonstrates the potential of reactor-based experiments for the $n \to \bar{n}$ transition search (since free-neutron transition is not suppressed by the difference of nuclear potential for neutron and anti-neutron). In 1982, one of us (W. Bugg) was involved in the development of a proposal (an effort led by Dick Wilson of Harvard University) to search for $n \to \bar{n}$ transitions at Oak Ridge research reactor (ORR). That proposal was not approved, since at that time the sensitivity of the designed experiment was not competitive with forthcoming intranuclear search opportunities. Presently Super-Kamiokande experiment has a chance to improve intranuclear $n \to \bar{n}$ search limit by factor of ~10 while the sensitivity of free-neutron search at the reactors can be improved by factor of ~1000. No other experiments are being performed or planned anywhere in the world to extend the study of $n \to \bar{n}$ transitions.

The experimental and theoretical situation for a baryon instability search, both for proton decay and $n \to \bar{n}$ transitions, was reviewed at a workshop organized at Oak Ridge in March 1996.

We believe that the experimental search for baryon instability through $n \to \bar{n}$ transitions at research reactors in the U.S. should proceed for several reasons:

- New sensitive searches for $n \to \bar{n}$ transition will explore stability of matter up to lifetimes ~ $10^{+35}$ years, an order of magnitude beyond the reach of contemporary nucleon-decay experiments. Discovery of $n \to \bar{n}$ transition would establish phenomena leading to a new physics at an energy scale of ~$10^{+5}$ GeV (beyond the range of colliders).

- Discovery of $n \to \bar{n}$ transitions could reveal new symmetries and test some of the "sacred" ones. For example, the left-right symmetry, broken in the Standard Model, might be restored. Such a discovery would have a major impact on unification models and would contribute to the understanding of baryon asymmetry of the universe. If the $n \to \bar{n}$ transition phenomenon exists, it will provide a unique opportunity to perform a most precise test of CPT symmetry through neutron-antineutron mass difference (as pointed out by Yu. Abov, F. Djeparov, and L. Okun in 1984) and to address experimentally the question of the gravitational equivalence of baryonic matter and antimatter.

- The U.S. has a research reactor (HFIR), at the Oak Ridge National Laboratory, with the highest thermal neutron flux in the world (the average thermal neutron flux at the Spallation Neutron Source will be more than an order of magnitude lower), and there exists at ORNL the required expertise to develop and perform an $n \to \overline{n}$ search with reactor neutrons.
- An $n \to \overline{n}$ search experiment using reactor neutrons has never been performed in the U.S.; there is also no competitive activity in the world.
- With present technology (focusing neutron reflector, cold neutron source) the increase in the discovery potential of an $n \to \overline{n}$ transition search (relative to the level achieved in previous experiments) by a factor of 1000 or higher can be anticipated. A single day of measurement at the HFIR reactor at ORNL would be equivalent in discovery potential to an entire year of running at the ILL reactor in the previous experiment. Estimated cost of HIFR-based experiment should be well below $50M.

We ask HEPAP to endorse a detailed study of the feasibility of an experiment to search for $n \to \overline{n}$ transition with sensitivity 1000 times better than existing limit.

With our sincere regards:


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