Search for N-Nbar Transitions in Underground Laboratory

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TRIGA reactor
Neutron $\rightarrow$ antineutron means $\Delta B = -2$

- Why it is interesting and important?
- Why in underground lab?
- How to do that and what can be expected?
What we are learning from ~30 years of proton decay search?

• no nucleon decay is observed
• exp. sensitivities are close to the limits set by the background
• original SU(5) is ruled out (Georgi and Glashow, 1974)
• several other GUT and SUSY-extended models are ruled-out or constrained
• theoretical predictions for certain PDK modes are “improved”
  from initial $\sim 10^{29}$ yr to $\geq 10^{34}$ yr
• gauge couplings in GUT do not unify without SUSY
• even with addition of SUSY the unification is not perfect (S. Raby, PDG 2004)
• conspiracy of GUT and SUSY models (←both not experimentally proven)
• do we believe in “Great Desert”?
• are we diligently exploring all alternative ideas and experimental options?
What is telling us that baryon number is not conserved?

Observed and yet unexplained
Baryon Asymmetry of the Universe (BAU)

Three ingredients needed for BAU explanation (A. Sakharov, 1967):

(1) Baryon number violation
(2) C and CP symmetry violation
(3) Departure from thermal equilibrium

BAU does not tell us how baryon number is violated.
Violation/decay modes are predictions of theoretical models.
How to decide what modes are relevant for BAU explanation?
Two types of baryon instability

In violation of baryon number the conservation of angular momentum requires that spin $\frac{1}{2}$ of nucleon should be transferred to another fermion (lepton or baryon), e.g. $\Delta B = \pm \Delta L$

That leads to the selection rule:
$$\left| \Delta (B-L) \right| = 0 \text{ or } 2$$

- In the Standard Model, in SU(5), and common SUSY extensions:
  $$\Delta (B-L) = 0 \text{ or } \Delta B = + \Delta L \text{ (nucleon } \rightarrow \text{ antilepton, e.g. } p \rightarrow e^+ \pi^0)$$

- Second possibility of $\left| \Delta (B-L) \right| = 2$ allows transitions with
  $$\Delta B = - \Delta L \text{ (nucleon } \rightarrow \text{ lepton), } \left| \Delta B \right| = 2, \text{ and } \left| \Delta L \right| = 2$$

Conservation or violation of $(B-L)$ might determine different mechanisms of baryon instability.
Is \((B-L)\) conserved?

- In our laboratory samples \((B-L) = \text{#protons} + \text{#neutrons} - \text{#electrons}\)

\((B-L) \neq 0\)

- However, in the Universe most of the leptons exist as, yet undetected, relic neutrino and antineutrino radiation (similar to CMBR) and conservation of \((B-L)\) on the scale of the whole Universe is still an open question

- Non-conservation of \((B-L)\) was discussed theoretically since 1978 by: Davidson, Marshak, Mohapatra, Wilczek, Chang, Ramond ...
Important Theoretical Discoveries

• Anomalous nonperturbative effects in the Standard Model lead to violation of lepton and baryon number (’t Hooft, 1976)

this $B$ and $L$ nonconservation in SM is too small to be experimentally observable at low temperatures, but was large at $T$ above electroweak scale.

• “On anomalous electroweak baryon-number non-conservation in the early universe” (Kuzmin, Rubakov, Shaposhnikov, 1985)

The anomalous SM interaction conserves ($B - L$) but violate ($B + L$). Rate of anomalous ($B + L$)-violating electroweak processes at $T > \text{TeV}$ (sphaleron mechanism) exceeds the Universe expansion rate. If $B = L$ would be set at very high temperature (e.g. at GUT scale) due to some ($B - L$) conserving interaction (e.g. by SU(5) SUSY proton decay), all quarks and leptons in the universe along with BAU will be wiped out by ($B + L$)-violating electroweak processes. Thus, for the explanation of BAU ($B - L$) violation at the scale above EW ($\approx 1 \text{ TeV}$) is required.
(B–L) needs to be violated at the scale above TeV

Violation of (B–L) implies nucleon instability modes:

\[ n \rightarrow \bar{n}, p \rightarrow \nu \nu e^+, n \rightarrow \nu \nu \bar{\nu}, \text{etc. or } \Delta(B - L) = -2 \]

Rather than conventional p-decay modes:

\[ p \rightarrow e^+ \pi^0, p \rightarrow \nu K^+, p \rightarrow \mu^+ K^0, \text{etc. or } \Delta(B - L) = 0 \]

If conventional (B–L)-conserving proton decay would be discovered e.g. by Super-K, it does not help us to understand BAU.

“The proton decay is not a prediction of the baryogenesis”

Yanagida @ v2002
### Ideas of 2005’s are different from 1980’s:

<table>
<thead>
<tr>
<th>1980’s</th>
<th>2005’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUT models conserving ((B-L)) were thought to work for BAU explanation</td>
<td>Proton decay is not a prediction of baryogenesis! [Yanagida’02]</td>
</tr>
<tr>
<td>[Pati &amp; Salam’73, Georgi &amp; Glashow’74…]</td>
<td>(\Delta(B-L)\neq 0) is needed for BAU [Kuzmin, Rubakov, Shaposhnikov’85…]</td>
</tr>
<tr>
<td>No indications for neutrino masses</td>
<td>(m_\nu \neq 0) […S-K’98, SNO’02, KamLAND’03] and possible Majorana nature of neutrino</td>
</tr>
<tr>
<td>Great Desert [Giorgi &amp; Glashow’74] from SUSY scale to GUT scale</td>
<td>No Desert. Possible unification with gravity at (\sim 10^5) GeV scale</td>
</tr>
<tr>
<td>((B-L)=0) in SM, SU(5), SUSY SO(10)…</td>
<td>((B-L)\neq 0) in ext. SUSY SO(10), L-R sym, QG</td>
</tr>
<tr>
<td>Energy scale: (10^{15}–10^{16}) GeV</td>
<td>Effective energy scale: above TeV</td>
</tr>
<tr>
<td>(\rightarrow p \rightarrow e^+\pi^0, p \rightarrow \bar{\nu}K^+, etc.)</td>
<td>(\rightarrow n \rightarrow \bar{n}, v_R, 2\beta0v, n \rightarrow 3v, etc.)</td>
</tr>
</tbody>
</table>
Spectacular work of Super-K, Soudan-2, IMB3, Kamiokande, Fréjus

All modes

\[ \Delta(B-L)=0 \]

2003, M. Shiozawa
28th International Cosmic Ray Conference
Some $\Delta(B-L)\neq 0$ nucleon decay modes (PDG’04)

<table>
<thead>
<tr>
<th>(B–L)$\neq 0$ modes</th>
<th>Limit at 90% CL</th>
<th>S/B</th>
<th>Experiment’year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p \rightarrow vve^+$</td>
<td>$&gt;1.7 \times 10^{31}$ yr</td>
<td>152/153.7</td>
<td>IMB’99</td>
</tr>
<tr>
<td>$p \rightarrow vv\mu^+$</td>
<td>$&gt;2.1 \times 10^{31}$ yr</td>
<td>7/11.23</td>
<td>Fréjus’91</td>
</tr>
<tr>
<td>$n \rightarrow e^+e^-\nu$</td>
<td>$&gt;2.57 \times 10^{32}$ yr</td>
<td>5/7.5</td>
<td>IMB’99</td>
</tr>
<tr>
<td>$n \rightarrow \mu^+\mu^-\nu$</td>
<td>$&gt;7.9 \times 10^{31}$ yr</td>
<td>100/145</td>
<td>IMB’99</td>
</tr>
<tr>
<td>$n \rightarrow vv\bar{\nu}$</td>
<td>$&gt;1.9 \times 10^{29}$ yr</td>
<td>686.8/656</td>
<td>SNO’04</td>
</tr>
<tr>
<td>$n \rightarrow \bar{n}$</td>
<td>$&gt;7.2 \times 10^{31}$ yr</td>
<td>4/4.5</td>
<td>Soudan-II’02</td>
</tr>
<tr>
<td>$nn \rightarrow \nu\bar{\nu}$</td>
<td>$&gt; 4.9 \times 10^{25}$ yr</td>
<td></td>
<td>Borexino’03</td>
</tr>
</tbody>
</table>

e.g. for $p \rightarrow vve^+$ with a lifetime $>1.7 \times 10^{31}$ yr
Super-K should detect ~ 430 events/yr

$n \rightarrow e^+e^-\nu$ mode with highest limit

$n \rightarrow vv\bar{\nu}$ $\Delta B = -1$ mode with lowest limit

$nn \rightarrow \nu\bar{\nu}$ $\Delta B = -2$ mode with lowest limit

$n \rightarrow \bar{n}$ mode with highest future potential
ΔB, ΔL≠0 searches in particle decays (PDG’2004)

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Limit (CL = 95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma(Z \to pe)/\Gamma_{\text{total}}$</td>
<td>$&lt;1.8 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Gamma(Z \to p\mu)/\Gamma_{\text{total}}$</td>
<td>$&lt;1.8 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Gamma(\tau^- \to \bar{p}\gamma)/\Gamma_{\text{total}}$</td>
<td>$&lt;3.5 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Gamma(\tau^- \to \bar{p}\pi^0)/\Gamma_{\text{total}}$</td>
<td>$&lt;1.5 \times 10^{-5}$</td>
</tr>
<tr>
<td>$\Gamma(\tau^- \to \bar{p}2\pi^0)/\Gamma_{\text{total}}$</td>
<td>$&lt;3.3 \times 10^{-5}$</td>
</tr>
<tr>
<td>$\Gamma(\tau^- \to \bar{p}\eta)/\Gamma_{\text{total}}$</td>
<td>$&lt;8.9 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Gamma(\tau^- \to \bar{p}\pi^0\eta)/\Gamma_{\text{total}}$</td>
<td>$&lt;2.7 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

- All above limits are Δ(B−L)=0 decay modes

- $\tau^- \to n + \pi^-$ would be an interesting alternative Δ(B−L) = +2 (e.g. for BaBar/Belle; observed branching $\sim 10^{-9}$ would indicate scale $\sim 10^5$ GeV)

- Note, that in other modes (e.g. $p \to e^+\nu\nu$) Δ(B−L) = −2
KamLAND is searching for $\Delta(B-L)\neq 0$ processes:

Neutron disappearance from $^{12}\text{C}$ (e.g. $n \rightarrow \nu\nu\bar{\nu}$) (small accidental background)

Expected sensitivity improvement to $7 \times 10^{29}$ yr
(current SNO limit is $\tau > 1.9 \times 10^{29}$ yr)

Two neutron disappearance from $^{12}\text{C}$ (e.g. $nn \rightarrow \nu\bar{\nu}$)
Expected sensitivity improvement to $1.7 \times 10^{30}$ yr
(current Borexino limit is $\tau > 4.9 \times 10^{25}$ yr)
Neutron $\rightarrow$ Antineutron Transitions

- $\Delta(B-L) = -2$ and $\Delta B = -2$
- Neutral $n$ state can mix with $\bar{n}$ state in vacuum
- Can be searched in vacuum transitions with free $n$
- Spectacular detection of annihilating $\bar{n}$
- No background in vacuum transitions search have been seen
- Intranuclear $n \rightarrow \bar{n}$ transition is followed by $\bar{n}$ annihilation
- Has the highest potential in exp. sensitivity improvement for B-violation search
Neutron $\rightarrow$ Antineutron Transition?

- The oscillation of neutral matter into antimatter is well known to occur in $K^0 \leftrightarrow \bar{K}^0$ and $B^0 \leftrightarrow \bar{B}^0$ particle transitions due to the non-conservation of strangeness and beauty quantum numbers by electro-weak interactions.

- There are no laws of nature that would forbid the $n \leftrightarrow \bar{n}$ transitions except the conservation of "baryon charge (number)":
  
  \begin{align*}
  &M. \text{ Gell-Mann and A. Pais}, \text{ Phys. Rev.} \ 97 \ (1955) \ 1387 \\
  &L. \text{ Okun}, \text{ Weak Interaction of Elementary Particles, Moscow, 1963}
  \end{align*}

- $n \leftrightarrow \bar{n}$ was first suggested as a possible mechanism for explanation of BAU (Baryon Asymmetry of Universe) by $V. \text{ Kuzmin, 1970}$

- First considered and developed within the framework of Unification models by $R. \text{ Mohapatra and R. Marshak, 1979}$
Observable neutron–antineutron oscillations in seesaw models of neutrino mass

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Received 12 August 2001; accepted 27 August 2001
Editor: M. Cvetic

Abstract

We show that in a large class of supersymmetric models with spontaneously broken $B-L$ symmetry, neutron–antineutron oscillations occur at an observable level even though the scale of $B-L$ breaking is very high, $v_{B-L} \sim 2 \times 10^{16}$ GeV, as suggested by gauge coupling unification and neutrino masses. We illustrate this phenomenon in the context of a recently proposed class of seesaw models that solves the strong CP problem and the SUSY phase problem using parity symmetry. We obtain an upper limit on $N-\bar{N}$ oscillation time in these models, $\tau_{N-\bar{N}} \lesssim 10^3-10^6$ s. This suggests that a modest improvement in the current limit on $\tau_{N-\bar{N}}$ of $0.86 \times 10^8$ s will either lead to the discovery of $N-\bar{N}$ oscillations, or will considerably restrict the allowed parameter space of an interesting class of neutrino mass models. © 2001 Published by Elsevier Science B.V.

For wide class of L-R and super-symmetric models predicted n-nbar upper limit is within a reach of new n-nbar search experiments! If not seen, n-nbar should restrict a wide class of SUSY models.
Quarks and leptons belong to different branes separated by an extra-dimension; proton decay is strongly suppressed, n-nbar is NOT since quarks and anti-quarks belong to the same brane.
Non-conservation of global charges in the Brane Universe and baryogenesis

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Proton decay is strongly suppressed in this model, but n-nbar is not since nR has no gauge charges.

Fig. 1. Creation of baby branes.

Fig. 2. Flux tube holding the baby brane with a local charge.
Effective $D = 7$ operators can generate $n$-$n\bar{n}$ transitions
n→n̅ transition probability

\[ \Psi = \begin{pmatrix} n \\ n̅ \end{pmatrix} \] mixed \ n - n̅ QM state

\[ H = \begin{pmatrix} E_n & \alpha \\ \alpha & E_n̅ \end{pmatrix} \] Hamiltonian on the system \( \alpha \)-mixing amplitude

where \( E_n \) and \( E_n̅ \) are non-relativistic energy operators:

\[
E_n = m_n + \frac{p^2}{2m_n} + U_n ; \quad E_n̅ = m_n̅ + \frac{p^2}{2m_n̅} + U_n̅
\]

**Important assumptions:**
- \( \alpha(n \rightarrow n̅) = \alpha(n̅ \rightarrow n) = \alpha \) (i.e. T-invariance is hold)
- there is a reference frame where \( p = 0 \)
- \( m_n = m_n̅ \) (if CPT is not violated)
- gravipotential for \( n \) and \( n̅ \) is the same: \( \Delta U = U_n - U_n̅ = 0 \)
- magnetic moment \( \mu(n̅) = -\mu(n) \) as follows from CPT \([\mu(n̅) \text{ not measured!}]\)
- Earth mag. field can be screened down to acceptable few \( nT \) level
n→nbar transition probability (for given \(\alpha\))

For \(H = \begin{pmatrix} m_n + V & \alpha \\ \alpha & m_\bar{n} - V \end{pmatrix}\) we have

\[
P_{n\rightarrow\bar{n}}(t) = \frac{\alpha^2}{\alpha^2 + (V + \Delta m/2)^2} \times \sin^2 \left[ \frac{\sqrt{\alpha^2 + (V + \Delta m/2)^2} t}{\hbar} \right]
\]

where \(V\) is a potential different for neutron and anti-neutron (e.g. due to non-compensated Earth mag. field; or part of gravipotential)
\(t\) is observation time in an experiment, and \(\Delta m = m_n - m_\bar{n}\)

In ideal situation of the "vacuum oscillations" \(V = 0\) and \(\Delta m = 0\)

\[
P_{n\rightarrow\bar{n}} = \left( \frac{\alpha}{\hbar t} \right)^2 = \left( \frac{t}{\tau_{n\bar{n}}} \right)^2
\]

\[
\tau_{n\bar{n}} = \frac{\hbar}{\alpha}
\]
is characteristic transition (oscillation) time \([\alpha < 10^{-23} eV]\)

"Sensitivity" \(\propto N_n \cdot < t^2 >\)

\((N_n\) number of neutrons used, \(t^2\) square of flight time)
PDG 2004: Limits for both free reactor neutrons and neutrons bound inside nucleus


Free n: M. Baldo-Ceolin et al., (ILL/Grenoble) Z. Phys C63 (1994) 409 with \( P = \left( \frac{t}{\tau_{\text{free}}} \right)^2 \)

\[ \tau_{\text{bound}} = R \cdot \tau_{\text{free}}^2 \]

where \( R \sim 10^{23} \text{ s}^{-1} \)

\( R \) is “nuclear suppression factor” Uncertainty of \( R \) from nuclear models is \( \sim \) factor of 2

Search with free neutrons is square more efficient than with bound neutrons

LIMIT ON \( n\bar{n} \) OSCILLATIONS

Mean Time for \( n\bar{n} \) Transition in Vacuum

A test of \( \Delta B = 2 \) baryon number nonconservation. MOHAPATRA 80 and MOHAPATRA 89 discuss the theoretical motivations for looking for \( n\bar{n} \) oscillations. DOVER 83 and DOVER 85 give phenomenological analyses. The best limits come from looking for the decay of neutrons bound in nuclei. However, these analyses require model-dependent corrections for nuclear effects. See KABIR 83, DOVER 89, ALBERICO 91, and GAL 00 for discussions. Direct searches for \( n \rightarrow \pi \) transitions using reactor neutrons are cleaner but give somewhat poorer limits. We include limits for both free and bound neutrons in the Summary Table.

<table>
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<th>VALUE (s)</th>
<th>CL%</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
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<td>&gt;1.3 \times 10^8</td>
<td>90</td>
<td>CHUNG 02B</td>
<td>SOU2</td>
<td>( n ) bound in iron</td>
</tr>
<tr>
<td>&gt;8.6 \times 10^7</td>
<td>90</td>
<td>BALDO-... 94</td>
<td>CNTR</td>
<td>Reactor (free) neutrons</td>
</tr>
<tr>
<td>1 \times 10^7</td>
<td>90</td>
<td>BALDO-... 94</td>
<td>CNTR</td>
<td>See BALDO-CEolin 94</td>
</tr>
<tr>
<td>&gt;1.2 \times 10^6</td>
<td>90</td>
<td>BERGER 90</td>
<td>FREJ</td>
<td>( n ) bound in iron</td>
</tr>
<tr>
<td>&gt;4.9 \times 10^5</td>
<td>90</td>
<td>BRESSI 90</td>
<td>CNTR</td>
<td>Reactor neutrons</td>
</tr>
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<td>See BRESSI 90</td>
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<td>CNTR</td>
<td>( n ) bound in oxygen</td>
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<td>90</td>
<td>HIDEACARO 85</td>
<td>CNTR</td>
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<td>CNTR</td>
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<td>BATTISTONI 84</td>
<td>NUSX</td>
<td></td>
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<tr>
<td>&gt;2.7 \times 10^7 - 1.1 \times 10^8</td>
<td>84</td>
<td>JONES 84</td>
<td>CNTR</td>
<td></td>
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<td>&gt;2 \times 10^7</td>
<td>83</td>
<td>CHERRY 83</td>
<td>CNTR</td>
<td></td>
</tr>
</tbody>
</table>
Experiment with free neutrons

Best reactor measurement at ILL/Grenoble reactor in 89-91
by Heidelberg-ILL-Padova-Pavia Collaboration

Schematic layout of Heidelberg - ILL - Padova - Pavia nn search experiment at Grenoble 89-91

with \( L \sim 90 \text{ m} \) and \( \langle t \rangle = 0.109 \text{ sec} \)

measured \( P_{nn} < 1.606 \times 10^{-18} \)
Detector of Heidelberg - ILL-Padova-Pavia Experiment @ ILL 1991
(size typical for HEP experiment)

No background!
No candidates observed.
Measured limit for a year of running:

\[ \tau_{n\bar{n}} \geq 8.6 \times 10^7 \text{ sec} \]

= 1 unit of sensitivity
N-Nbar in Underground Lab

(B –L) violation physics search at Underground Labs:

- in nucleon decay experiments: \( n \rightarrow \nu \nu \bar{\nu}, \ p \rightarrow e^+ \nu \nu \)
- in double-beta decay \( \Delta L=2 \)
- most spectacular in n-nbar \( \Delta B=2 \)

- Most important motivation for N-Nbar: sensitivity can be increased by factor > 1,000 relative to the present level of ILL/Soudan-II
- Magnificent detection signature: \( \sim 1.8 \) GeV annihilation star of 5 pions
- No background: one event = discovery!
- \( P = \left(\frac{t}{\tau_{\text{free}}}\right)^2 \) with \( t \) (time of flight) 0.1 sec \( \rightarrow \) 1 sec
- Enhance cold neutron flux by neutron focusing
- Vertical layout saves focusing
Scheme of N-Nbar search experiment with vertical layout

- Dedicated small-power research reactor with cold neutron moderator → $V_n \sim 1000$ m/s
- Vertical shaft ~1000 m deep with diameter ~ 6 m at DUSEL
- Large vacuum tube, focusing reflector, Earth magnetic field compensation system
- Detector (similar to ILL N-Nbar detector) at the bottom of the shaft (no new technologies)
- Inverse scheme with reactor at the bottom and detector on the top of the mine shaft is also feasible
- Construction ~ 4 years; running time ~ 3 years

Not to scale
Annular core TRIGA reactor (GA) for N-Nbar search experiment

- GA built ~ 70 TRIGA reactors 0.01÷14 MW (th)
- 19 TRIGA reactors are presently operating in US (last commissioned in 1992)
- 25 TRIGA reactors operating abroad (last commissioned in 2005)
- some have annular core and vertical channel
- most steady, some can be pulsed up to 22 GW
- safe ~ 20% EU uranium-zirconium hydride fuel

Economic solution for n-nbar:
annular core TRIGA reactor 3.4 MW with convective cooling, vertical channel, and large cold LD₂ moderator (Tₙ ~ 35K).
Unperturbed thermal flux in the vertical channel ~ 2×10¹³ n/cm²/s

Courtesy of W. Whittemore
(General Atomics)
### $n \rightarrow \bar{n}$ Search Sensitivity

Soudan-II limit ≈ ILL/Grenoble limit = 1 unit of sensitivity

<table>
<thead>
<tr>
<th>Method</th>
<th>Present limit</th>
<th>Possible future limit</th>
<th>Possible sensitivity increase factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intranuclear (N-decay expts)</td>
<td>$7.2 \cdot 10^{31}$ yr = 1 unit Soudan II</td>
<td>$7.5 \cdot 10^{32}$ yr (Super-K)</td>
<td>$4.8 \cdot 10^{32}$ yr (SNO)</td>
</tr>
<tr>
<td>Geo-chemical (ORNL)</td>
<td>none</td>
<td>$4 \cdot 10^8 \div 1 \cdot 10^9$ s (Tc in Sn ore)</td>
<td>× 20 – 100</td>
</tr>
<tr>
<td>UCN trap (6×10$^7$ ucn/sec)</td>
<td>none</td>
<td>$\sim 1 \cdot 10^9$ s</td>
<td>× 100</td>
</tr>
<tr>
<td>Cold horizontal beam</td>
<td>$8.6 \cdot 10^7$ s = 1 unit @ILL/Grenoble</td>
<td>$3 \cdot 10^9$ s (HFIR@ORNL)</td>
<td>× 1,000</td>
</tr>
<tr>
<td>Cold Vertical beam</td>
<td>none</td>
<td>$3 \cdot 10^9 \div 1 \cdot 10^{10}$ s (Underground Lab)</td>
<td>&gt; 1,000</td>
</tr>
</tbody>
</table>

There is no competition in the world 🆙
Stability of matter from Neutron-Antineutron transition search

\[ T_A = R \times (\tau_{\text{free}})^2, \text{ where } R \text{ is "nuclear suppression factor" in intranuclear transition} \]
Science impact of n-nbar search

**If discovered:**

- $n \rightarrow n \bar{n}$ will establish a new force of nature and a new phenomenon leading to the physics at the energy scale of $\sim 10^5$ GeV
- will provide an essential contribution to the understanding of BAU
- might be the first detected manifestation of extra dimensions and low QG scale
- new symmetry principles can be experimentally established: $\Delta(B-L) \neq 0$
- further experiments with free neutrons will allow high-sensitivity testing
  - whether $m_n = m_{\bar{n}}$ (CPT theorem) with $\Delta m/m \approx 10^{-23}$ *(L. Okun et al, 1984)*
  - gravitational equivalence of baryonic matter and antimatter *(S. Lamoreaux et al, 1991)*

**If NOT discovered:**

- within the reach of improved experimental sensitivity will set a new limit on the stability of matter competitive to X-large nucleon decay experiments
- wide class of SUSY-based models will be removed *(K. Babu and R. Mohapatra, 2001)*