Community Summer Study 2013

Snowmass on the Mississippi

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Neutron-antineutron oscillations vs nuclei stability

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Intro

K. S. Babu presented theoretical motivations for neutron-antineutron oscillations.

$\Delta B = 2$ analog of the search for Majorana neutrino, $\Delta L = 2$.

Experimental limits on stability of nuclei set the range of interest for the free neutron oscillation time $\tau_{n\bar{n}}$.

Super-K (2011) $\quad \tau(^{16}O) > 1.97 \times 10^{32}$ yr

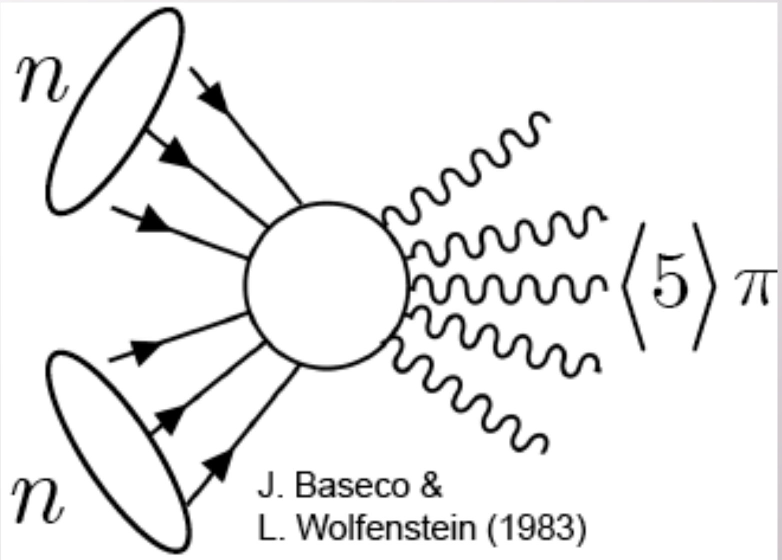
Theory, Friedman, Gal (2008), relates it to $\tau_{n\bar{n}}$,

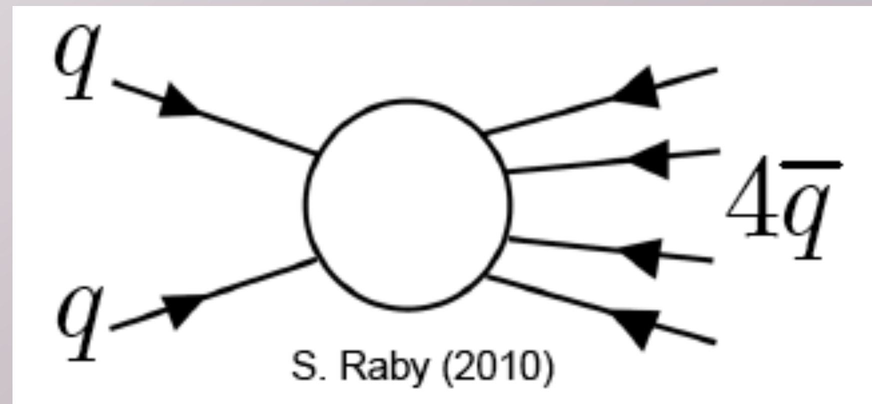
$$\tau_A = R\,\tau_{n\bar{n}}^2 \qquad R = 5 \times 10^{22}\ s^{-1} \qquad \tau_{n\bar{n}} > 3.53 \times 10^8\ \mathrm{s}$$

Free neutron ILL experiment (1994)

$$\tau_{n\bar{n}} > 0.86 \times 10^8\ \mathrm{s}$$

Number of extra mechanisms was proposed, in particular,





How much it affects the relation between $\tau_{n\bar{n}}$ and τ_A ?

To answer we try some independent approach based on the Operator Product Expansion.

Operators |ΔB|=2

The operators contains two u quarks and four d quarks

$$\mathcal{O}_{\Delta B=-2} = uudddd$$

Each quark has color and spinor indices and could be left- or right-handed

$$q^i_{L\alpha}\,, \quad q^k_{R\dot{\alpha}}\,, \qquad i,k = 1,2,3, \quad \alpha,\dot{\alpha} = 1,2$$

Color indices convoluted with two ϵ_{ijk} and spinor indices with $\epsilon^{\alpha\beta}$ or $\epsilon^{\dot{\alpha}\dot{\beta}}$.

Rao and Shrock introduced in 1982 the basis consisting of 18 operators.

$$\mathcal{O}^1_{\chi_1\chi_2\chi_3} = (u^i_{\chi_1} u^j_{\chi_1})(d^k_{\chi_2} d^l_{\chi_2})(d^m_{\chi_3} d^n_{\chi_3}) T^s_{ijklmn}$$

$$\mathcal{O}^2_{\chi_1\chi_2\chi_3} = (u^i_{\chi_1} d^j_{\chi_1})(u^k_{\chi_2} d^l_{\chi_2})(d^m_{\chi_3} d^n_{\chi_3}) T^s_{ijklmn}$$

$$\mathcal{O}^3_{\chi_1\chi_2\chi_3} = (u^i_{\chi_1} d^j_{\chi_1})(u^k_{\chi_2} d^l_{\chi_2})(d^m_{\chi_3} d^n_{\chi_3}) T^a_{ijklmn}$$

Here $\chi = L, R$ and color tensors are

$$T^s_{ijklm} = \epsilon_{ikm}\epsilon_{jln} + \epsilon_{ikn}\epsilon_{jlm} + \epsilon_{jkm}\epsilon_{nil} + \epsilon_{jkn}\epsilon_{ilm}$$

$$T^a_{ijklmn} = \epsilon_{ijm}\epsilon_{pkln} + \epsilon_{ijm}\epsilon_{klm}$$

Caswell, Milutinovic and Senjanovic showed in 1983 that

$$\mathcal{O}^2_{\chi\chi'} - \mathcal{O}^1_{\chi\chi'} = 3\,\mathcal{O}^3_{\chi\chi'}$$

what diminishes the number of operators to 14.

It is clear that not all of these operators contribute to the free $n \leftrightarrow \bar{n}$ oscillations.

In particular, only parity changing ones

$$\mathcal{O}_{\chi_1\chi_2\chi_3} - (L \leftrightarrow R)$$

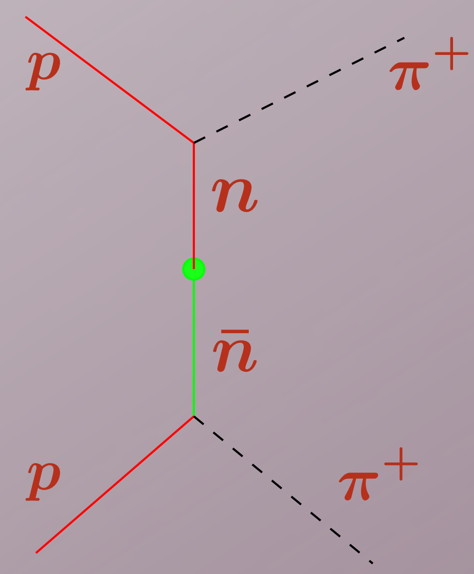
are relevant what takes away a half of operators.

Also the operators differ by isospin, $\Delta I = 1, 2, 3$, while the oscillations are due to $\Delta I = 1$ only.

But for nuclei both parity conserving operators as well as the $\Delta I = 2, 3$ ones do contribute via two nucleons annihilation into pions.

Thus, one can imagine the case of unstable nuclei and no free $n \leftrightarrow \bar{n}$ oscillations. So there is a complimentarity of measurements of oscillations and nuclear stability.

On the other hand, there are processes in nuclei involving not only real but also the virtual $n \leftrightarrow \bar{n}$ transition which contribute to the nuclear instability.



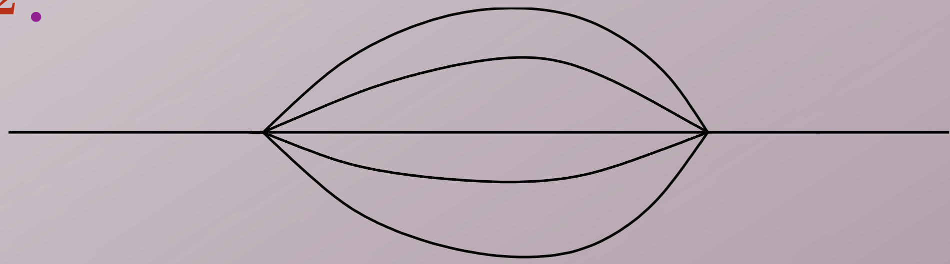
Estimates

Let us try to use some kind of duality to find a relation between the free $n \leftrightarrow \bar{n}$ oscillations and nuclear stability.

$$\langle \bar{n} | c_{\mathcal{O}} \mathcal{O} | n \rangle = \epsilon \bar{u}^c_{\bar{n}} \gamma_5 u_n \,, \quad |\epsilon| = \frac{\hbar}{\tau_{n\bar{n}}}$$

where $\mathcal{O}$ decreases B, $\Delta B = -2$.

Operator product expansion

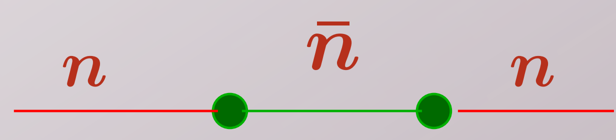


$$\int d^4x \, \mathrm{e}^{iqx} T\{\mathcal{O}(x)\mathcal{O}^\dagger(0)\} = c_q \, \bar{q}q + \ldots$$

The average over a nucleus A gives its lifetime τ_A

$$2|c_{\mathcal{O}}|^2 \mathrm{Im} \int d^4x \langle A | T\{\mathcal{O}(x)\mathcal{O}^\dagger(0)\} | A \rangle = \frac{\hbar}{\tau_A}$$

The average over neutron state



$$|c_{\mathcal{O}}|^2 \int d^4x\, e^{iqx} \langle n|T\{\mathcal{O}(x)\mathcal{O}^\dagger(0)\}|n\rangle \sim \frac{|\epsilon|^2}{\Delta}$$

where Euclidean $q \sim \Delta$ is a relevant hadronic duality scale.

Taking $\langle A|\bar{q}q|A\rangle \sim A\,\langle n|\bar{q}q|n\rangle$ for the leading OPE term we get

$$\tau_A = R\,\tau_{n\bar{n}}^2\,, \quad R = \frac{\Delta}{A\hbar}$$

For ^{16}O and an educated guess for $\Delta = 0.5\ \mathrm{GeV}$

$$R = 4.7 \times 10^{22}\ s^{-1}$$

what is close to the result obtained by Friedman, Gal (2008).

The inclusive approach does include all the mechanisms.

The above estimate implies that the contribution of processes not associated with the $n \leftrightarrow \bar{n}$ oscillations, such as two nucleons annihilation into pions are suppressed.

This suppression related to the notion of nuclei consisting of nucleons not of quarks. Parametrically, it could be written as

$$\frac{p_{nucl}^2}{p_{hadr}^2}$$

where p_{nucl} represents the characteristic nuclear momentum (distance between nucleons) while p_{hadr} refers to the hadronic momentum scale (the nucleon size). The suppression could be not that big in reality.

Conclusions

Generically, nuclear disappearance lifetimes are sensitive to a wider variety of the $|\Delta B| = 2$ processes then neutron-antineutron oscillations.

There is a nuclear suppression for this non-oscillation part in the nuclei instability.

What is the theoretical accuracy? Needs more work.