A LIMIT ON RADIATIVE DECAYS OF ν_e's IN MATTER

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ABSTRACT

An exploratory search of ν_e radiative decays in a germanium crystal was performed at the Bugey reactor plant. No signal was found and a limit is set at a level excluding this phenomenon as a possible cause of the solar neutrino deficit.

1. Motivation

The possibility of radiative decays of solar neutrinos on their way to the earth was advocated long ago in order to explain the solar deficit. This solution was clearly ruled out with the result obtained with the SN1987A explosion. The limit is [1]: $\tau/m > 6\ 10^{15}$ s/eV. This is much larger than the 500 s of flight path between the sun and the earth. The limit applies to $\bar{\nu_e}$, since only $\bar{\nu_e}$ have been clearly detected from the supernova. Moreover this limit is only valid for neutrinos having a strong mass hierarchy, the search being done for photons carrying about half of the incident neutrino energy.
To overcome this limitation, a second search was done at the Bugey reactor [2] looking for visible or nearly visible photons. The result excludes the decay as a possible explanation of the solar deficit in a scheme of mass-degenerate neutrinos for a domain of masses $\delta m/m > 10^{-7}$, where δm is the difference of the two masses and m is the nearly common neutrino mass. Being obtained at a reactor, the limit again applies to antineutrinos.
These searches correspond to decays in vacuum. Recent calculations have shown that neutrino radiative decays can be hugely amplified in a dense medium [3]. The sun has a density as high as 150 gcm^{-3} in its center, and a new possibility arises: could neutrinos decay in the sun interior? A deficit of 50% compared to expectations would require a boosted distance $\gamma c\tau$ of the order of 500000 km. For neutrinos of 10 MeV this corresponds to a lifetime in matter of 2 10^{-7} s/eV. This is not excluded experimentally, and the spectrum measured by the SuperKamiokande collaboration [4] in the region 6-15 MeV cannot exclude it because of the limited energy resolution of its detection.

2. The ν_e beam

The sun produces neutrinos of type ν_e . The amplification process of the radiative decay is due to matter effects. In matter, the index of refraction is different for

neutrinos and antineutrinos. This is why we chose to test the idea of stimulated decays in matter directly with a beam of ν_e's.
It is well known that nuclear reactors are powerful sources of $\bar{\nu_e}$. It is less known that they are also sources of ν_e [5]. This comes about because of neutron activation of the containment vessel and of the core itself. In particular the isotopes ^{55}Fe and ^{51}Cr are produced abondantly. They decay through electron capture, and the resulting spectrum consists of a series of lines. ^{55}Fe produces ν_e of 230 keV energy with a half-life of 2.6 years, while ^{51}Cr produces ν_e of 750 keV with a half-life of 28 days. At equilibrium, the flux of each of these two components represents 2.5 10^{-4} that of the antineutrinos coming from fission reactions. After the reactor stop, the $\bar{\nu_e}$ flux disappears but the ν_e flux stays on for a long time.

3. Experimental set-up

We have used a high purity germanium (HPGe) coaxial diode from Eurisys [6] of effective volume 140 cm^3 cooled at liquid nitrogen temperature. Germanium is a semiconductor having an intrinsic band gap of 0.74 eV and a mean electron-hole pair creation work of 3 eV. The Ge crystal was chosen of the P type, the Li dopped zone giving some protection against alphas and low energy betas and gammas from natural radioactivity. This protection was enforced by a 3 cm thick lead shield surrounding the detector. The whole set-up was supported by 4 pneumatic isolators.
The experiment consisted in searching for photons produced in the decay of monoenergetic ν_e's inside the crystal. The chosen detector is well adapted to the search presented here. Germanium has a high density of 5.3 gcm^{-3}, and it gives a good energy resolution on photons produced within its volume.
The crystal was installed at a distance of 15 m from the second reactor of the Bugey plant. At this distance the flux of ν_e's is 4.25 $10^9/cm^2$ per second for each of the two peaks at 230 keV and 750 keV. For the dimensions of the crystal, and for the 4200 s livetime of the exposure, the total flux traversing the detector is 5 10^{14} ν_e's. The detector was calibrated with radioactive sources. The impulsional energy resolution is 6 keV FWHM on the 1.33 MeV ^{60}Co line.

4. Analysis

We looked for the two-body decay:

$$\nu_e \rightarrow \nu' + \gamma$$

in the case of a negligible mass for the final neutrino. In the rest frame the photon takes the energy m/2 where m is the mass of the decaying neutrino. For Majorana neutrinos the decay is isotropic, and the photon energy is flat in the laboratory frame between 0 and the full neutrino energy. For Dirac neutrinos, a slight anisotropy is possible, and this results in a change in the spectrum of the decay photon. The

result obtained here for Majorana neutrinos still applies within a factor 2 for Dirac neutrinos.
The figure 1 shows the spectrum obtained at the end of the data taking. Decaying neutrinos would produce an excess of photons with a flat contribution giving a first step at 230 keV and a second one at 750 keV. No such signal is visible. Evaluating the maximum contribution of a flat component, one can extract the 90% limit:

$$\tau/m > 3\ 10^{-4}\ \mathrm{s/eV}$$

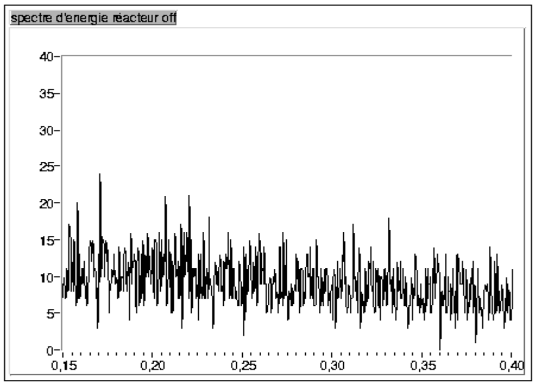

Figure 1: *Measured spectrum*

5. Conclusion

We performed a first search of radiative decays of ν_e's in matter. This was done by exposing a high purity germanium crystal to the beam of the Bugey reactor. A nuclear reactor offers a powerful source of monoenergetic ν_e's having energies comparable to solar neutrinos energies. A previous search was done at the Goesgen reactor [7] but the result is not applicable since it relies on the reactor on minus reactor off method, and is only valid for $\bar{\nu}_e$'s. Another limit coming from Los Alamos [8] directly applies to ν_e's but it was obtained with higher energy neutrinos (30 MeV) and in a light calorimeter.
The present result excludes the possibility of a substantial decay of ν_e's in the sun interior.
The amplification factor of radiative decays in matter is:

$$8.6\ 10^{23} F(v)(N_e/10^{24} cm^{-3})^2$$

with N_e being the electron density of the medium, and F(v)= 4m/E for relativistic neutrinos. This formula applies for neutrinos of 1 eV mass. For an energy of 230 keV, the amplification factor applicable to our conditions is $2.9\,10^{19}$. Applying this factor to our result, the limit becomes:

$$\tau > 9\ 10^{15}\ \mathrm{s}$$

for the equivalent half-life of a 1 eV neutrino in vacuum.

6. References

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