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PeP-neutrino Detection by Lithium Detector as a Direct Way to Search for Oscillation of Solar Neutrinos.

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Abstract.

The high sensitivity of lithium detector to pep- and ^{7}Be-neutrinos makes a lithium radiochemical detector a powerful tool for the search of the oscillations of solar neutrinos.The first phase of lithium experiment on the installation with 10 tons of metallic lithium will enable to collect data within 1 year of measurements to provide very definite information about SMA MSW solution. The second phase with 10 modules 10 tons each will measure the semiannual variations of the signal, thus the contributions of pep- and ^{7}Be-lines will be weighted, what will give a ?smoking-gun? evidence about ?just-so? solution for large mixing angles and Dm^2 about 10^{-10}-10^{-9} eV^2. If both regions are not confirmed the results of lithium detector can be interpreted in favor of LMA MSW solution.

1. Introduction.

Recent results obtained by SuperKamiokande [1] compared with the earlier results of four solar neutrino experiments [2] reveal three possible regions for the oscillation of solar neutrinos: MSW SMA, MSW LMA and ?just-so? region of vacuum oscillations with large mixing angle. So far the experimental data does not provide the ?smoking-gun? evidence which would enable to select one out of three regions. The further collection of statistics will hardly give a breakthrough in this direction, so still some ambiguities will remain, especially if to take into consideration that one can not exclude completely that in at least one of the previous experiments there?s unaccounted systematic error. So any experiment which can distinguish with high reliability between these three possibilities is now very valuable. Big expectations are assigned to another experiments which are coming soon in operation: SNO detector in Canada [3] and Borexino in Italy [4]. The potentials of these detectors are great, but experimental difficulties associated with the methods chosen are not less great. So far it is rather difficult to predict what will be the net result and whether the ambiguities due to the systematic errors will be eliminated to the extend the solution of the solar neutrino problem demands. Another possibility is the LENS project [5] and it is highly desirable to get the results from a pilot LENS installation to understand the real potential of this project. Another perspectives are associated with HELLAZ project [6] as a solar neutrino spectrometer with a good energy resolution and very low threshold. But as for any other electronic detector the question of the background is a very crucial point. Raymond Davis, who opened

this world of the solar neutrino research, used to point out that although a radiochemical detector is not an ideal one (does not give a signature of the event, a time resolution is not high etc.) has several substantial advantages: the sources of the background are very limited and thus the background can be predicted with high accuracy, the threshold is determined by the neutrino capture reaction, not by the instrumentation used. When people discuss the radiochemical detectors they usually say that one substantial limitation of these detectors is that here the integral result over all neutrinos with energy higher than a threshold is measured, that the contribution of different sources can not be found. I will illustrate in this paper that this statement is not always true, that in a certain case (or cases) what seems to be impossible is really possible. I will show that lithium radiochemical detector will give very definite information which will enable to distinguish between three possible regions of the solar neutrino oscillations, and the whole work will take only a few years. But of course to perform this complex task the efforts of several institutions are needed, the close cooperation of several laboratories on a wide spectrum of chemical and physical problems, from a metal technology till a cryogenics. Luckily the lithium project is not a very expensive one.

2.What lithium detector is?

Lithium detector was proposed by John Bahcall [7]. Main advantage of lithium as a target is that the cross-section of the neutrino capture reaction for the ground state of ^{7}Be

$^7Li + n_e \rightarrow {}^7Be + e^-$ (1)

and for the first excited state of ^{7}Be

$^7Li + n_e \rightarrow {}^7Be^* + e^-$ (2)

is guaranteed by well established isospin connections between mirror nuclei. The threshold for neutrino capture reaction on lithium is 0.862 MeV. Both transitions (to ground state and to the first excited state) are superallowed. The precise calculation of neutrino capture cross-section on ^{7}Li was done by J.Bahcall [8,9]. The relative contributions of transitions to the first excited state of ^{7}Be are about 5% for the ^{15}O and ^{65}Zn spectra (^{65}Zn neutrino source (E_n=1.343 MeV) proposed by L.Alvarez is planned to be used for calibration of lithium detector), 7% for pep-neutrinos, and about 21% for the average ^{8}B spectrum (^{13}N neutrinos do not have sufficient energy to populate the excited state). The contribution of the excited states above the first one to the total cross-section for solar neutrinos is negligible. Because both transitions are superallowed the cross-section for neutrino capture is relatively high: for pep-neutrinos (E_n =1.44 MeV), $s = 6 \times 10^{-44}$ cm^2, for ^{65}Zn source (E_n =1.343 MeV) $s = 2.25 \times 10^{-44}$ cm^2. It is clear from these numbers that lithium is a highly sensitive detector of solar neutrinos and the threshold is exactly what one needs: high enough not to see pp-neutrinos but low enough to see all intermediate energy range. In fact as it will be shown later with only ten tons of lithium in metallic form the 6.5% accuracy can be obtained within one year of measurements. And what makes a lithium detector very attractive is the selectively high sensitivity to pep-neutrinos. It happens because of the following. As one can see from Table 1, the intensity of ^{7}Be-line in the solar neutrino spectrum is about 35 times higher than intensity of pep-line. But for lithium target neutrinos from the decay of ^{7}Be have exactly threshold energy if one neglects electron screening in terrestrial atoms and thermal energy in the Sun. In fact, if

one includes electron screening in terrestrial atoms, but not thermal energy, then neutrinos from ^{7}Be in the Sun are below threshold and the absorption cross-section is zero. It was first shown by G.Domogatsky [10] that the thermal average over the energy distribution of the electrons captured in the Sun is important for ^{7}Be neutrinos incident on ^{7}Li. The differential cross-section for the electron capture process with the production of a neutrino of energy q, ds/dq, must be computed by taking into account of the thermal motion of both the ^{7}Be ions and the electrons. (The lithium cross-sections we are using here are a private communication from J.Bahcall , since recently he has made improvements in his calculations over the past 20 years.) Because of this effect the lithium detector is also sensitive to ^{7}Be neutrinos and for the predictions of Standard Solar Model the weights of these neutrinos and pep-neutrinos are comparable, see Table 1

Table 1. Standard Model Predictions (BP98): solar neutrino fluxes and neutrino capture rates for Li, with 1s uncertainty. The fluxes of pp- and pep-neutrinos are predicted with uncertainty of 1%. The contribution of CNO-cycle to the total energy generation in the Sun is strictly limited by the results of helioseismology.

Source	Flux (10^{10} cm^{-2}s^{-1})	Capture rate on ^{7}Li, SNU
pp	5.94 (1+0.01/-0.01)	
pep	1.39×10^{-2} (1+0.01/-0.01)	9.1
^{7}Be	4.80×10^{-1} (1+0.09/-0.09)	9.1
^{8}B	2.44×10^{-4} (1+0.03/-0.03)*	9.5
^{13}N	6.05×10^{-2} (1+0.19/-0.13)	2.6
^{15}O	5.32×10^{-2} (1+0.22/-0.15)	13.1
Total:		43.4

*) Flux measured by SuperKamiokande if all neutrinos are of electron type.

The comparison of the results of chlorine[2] and SK[1] experiments shows that there is a deficit of ^{7}Be neutrinos (this is in a good agreement with the results of gallium experiments [2] as well) which means that the expected contribution of these neutrinos in lithium is substantially lower. But, since the flux of ^{7}Be neutrinos is model dependent, we don?t know exactly what is the explanation of this deficit, whether it is due to some unknown character of the processes inside the Sun or it is manifestation of neutrino oscillations. To define this with high reliability we need some ?standard? line which is directly connected with the luminosity of the Sun and the only possibility here is pep-neutrinos.

3.What lithium experiment is aiming for?

There are two phases of lithium experiment which we are planning now: the first phase with one module on 10 tons of metallic lithium and the second phase with 10 modules 10 tons each. The second phase will start only if the first phase is completed with a full success. The primary aim of the first phase is to measure the flux of the medium energy solar neutrinos. The contribution of boron neutrinos is just a background known with a good accuracy from the results of SuperK (see table 1.). The minimal signal of lithium detector is composed of three parts: 9.5 SNU give boron neutrinos, 9.1 SNU come from pep-neutrinos and some contribution from ^{7}Be-line. If to compare the results of chlorine detector and SuperK one can deduce that the flux of beryllium neutrinos is by no means more than 20% of the Standard Solar Model (SSM) predictions. Here we will accept as an extreme case that the in-Sun-generated flux of ^{7}Be-line as low as 20% of SSM is not excluded assuming that to reject this possibility one needs direct experimental evidence. Thus the total minimal signal is about 20 SNU. If the experiment observes the signal less than 20 SNU, say, 10 SNU, this will be the evidence of strong attenuation of medium energy neutrinos from the Sun what conforms with MSW SMA solution. If we get more it will be necessary to find a way to distinguish between MSW LMA and ?just-so? regions. The presence of two lines in the spectrum of solar neutrinos with different energies (0.862 MeV for ^{7}Be-line and 1.44 MeV for pep-line) with the equal capture rates (according to SSM) on a lithium target gives a good opportunity for lithium detector to distinguish between these solutions. In fact for the ?just-so? case there should be observed the semiannual variations of the signal with the characteristic harmonics for each of these lines and for large mixing angles the modulation will be very deep (there will be of course some smearing by boron- and CNO-neutrinos with continuous spectra). Just to illustrate this possibility fig.1 shows the curves for pep-,^{7}Be-lines and the sum of them for the ?just-so? case following the expression:

$$P(n_e \; ? \; n_e) = 1 - \sin^2 2q \sin^2 (1.9\ 10^{11} Dm^2 R(t)/E),$$

here R(t) = 1 + 0.01675 cos (pt), t varies from -1 till +1, t = 0 corresponds to perihelion. One can see from this figure that the curves corresponding to pep- and ^{7}Be-lines have very different harmonics, so it is possible to weight the contributions of these neutrino sources in radiochemical lithium detector if to have a good statistics. This opens excellent possibilities for lithium detector. Not only the ?just-so? region can be confirmed or rejected and $\sin^2 2q$ and Dm^2 can be found but we will get also very valuable information on the generation spectrum of ^{7}Be-line what is very important for the solution of the solar neutrino problem in a pure astrophysical aspect. Having the flux of boron neutrinos from the results of SuperK we can find the contribution of each neutrino source detected by lithium detector: pep, ^{7}Be and CNO. At certain $\sin^2 2q$ and Dm^2 probably it will be even possible to detect the effect of smearing of the signal due to the large radius of active zone of the Sun where neutrinos are generated. If so it will give the direct information about the structure of the Sun. Because we need a good statistics in this case, this will be the aim of the second phase lithium experiment - with 10 modules 10 tons each. It doesn?t look fantastically at all, if the cost of gallium would be as low as the cost of lithium, the GNO experiment would work now on the 300-400 tons scale.

If neither MSW SMA nor ?just-so? regions are observed the results of lithium detector will be interpreted in favor MSW LMA solution. Thus for all three possible regions the results of lithium detector will be the valuable information.

The statistics of lithium detector is of course very different for phase I and phase II.

Phase I. 10 tons of lithium @ 20 SNU. One year of measurements, one year - for the calibration with ^{65}Zn-neutrino source.

Time of exposure 3 months, extraction efficiency 90%, counting efficiency 95%, counting within 5 half-lives. Statistical accuracy (1s) in one Run -13%. Four Runs per year, the total accuracy for one year measurements 6.5%.

Phase II. 10 modules 10 tons each @ 20 SNU.

Time of exposure 2 months, 6 Runs per year. 4.5% accuracy in each Run. The accuracy of each two-months point for 5 years of measurements - 2%. If the modulation of the signal is deep the positive evidence can be obtained within 1-2 years.

4.The present status of lithium detector.

The work on radiochemistry of lithium detector started quite a long time ago [11,12]. It was shown that beryllium can be efficiently extracted both from lithium chloride aqueous solution (K.Rowly) and from metallic lithium (E.Yanovich et.al). For many years the main problem for the realization of this project was the problem of counting of extracted atoms of ^{7}Be. For the solar neutrino experiment it is necessary to have the counting system with the efficiency close to 100% and this is very difficult to realize with conventional detectors because the energy of Auger-electrons during e-capture of ^{7}Be is only 55 eV. The major breakthrough came after the success of the counting of ^{7}Be by means of a cryogenic detector which was achieved in collaboration with the Genoa group in Italy [13,14]. After this it became clear that lithium program can be realized although a lot of efforts should be done to make the detector working. Now the R&D work is in progress on a basis of the prototype of lithium detector on 300 kg of metallic lithium which is conducted in Institute of Nuclear Research at Troitsk together with Institute of Physics and Power Egenering at Obninsk. The present status of this work is presented in a number of articles [15]. The main obstacle is the lack of a financial support. The participation of another laboratories interested in this program is vital for the success of the whole experiment. We hope that people will join the program taking into consideration the importance of the task and good perspectives for this detector.

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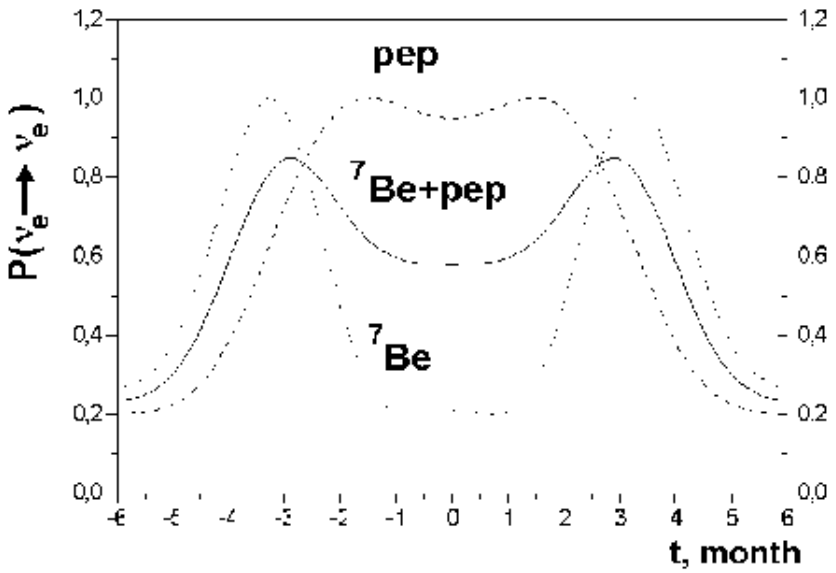

Fig.1. The semiannual variations of the signal for pep, ^{7}Be and pep+^{7}Be neutrinos ($\Delta m^2 = 4x10^{-10} eV^2$, $Sin^2 2\theta = 0.8$).