Geochemical Detection of the pp-Neutrino flux with ^{205}Tl LOREX collaboration

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Determination the probability for capturing Solar neutrinos on ^{205}Tl leading to the first excited state in ^{205}Pb

An indispensable goal of this proposal still remains the determination of the neutrino capture probability by ^{205}Tl. The ratio $^{205}Pb/^{205}Tl$ in lorandite provides only the product of solar neutrino flux and neutrino capture probability into the different nuclear states of ^{205}Pb (Fig.1).

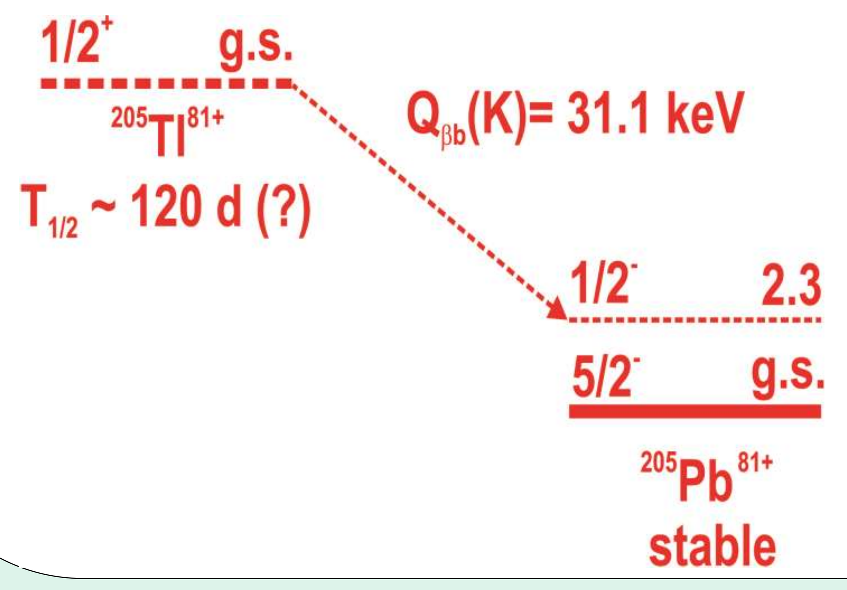

Fig.1. Decay scheme of neutral ^{205}Pb atoms (black) and of bare $^{205}Tl^{81+}$ ions (red). Whereas neutral ^{205}Pb atoms decay by unique first-forbidden orbital electron capture (EC) from the L and higher electron shells to stable neutral ^{205}Tl atoms with a half-life of 17.3 million years and a Q value of 50.5 keV, bare $^{205}Tl^{81+}$ (or H-like $^{205}Tl^{80+}$) ions can decay to almost 100% by β_b decay to the first excited state of ^{205}Pb-205^{81+} at E^*=2.3 keV, where the generated electron will be captured into the K shell [3].

Collection of sufficient amount, around several kilograms, of lorandite and to determine background contributions producing ^{205}Pb

The activities should be directed in such a way that the following estimates are ensured:
(i) Minimal quantity of pure lorandite, which guarantees a successful determination of ^{205}Pb after the separation of Pb (SADM – Single Atom Detection Methods);
(ii) The estimate of the expected error of measurements of ^{205}Pb and
(iii)The dependence of the number of ^{205}Pb atoms from paleo-depth, i.e. from the acuracy of erosion rate determinations *e* [4].

Taking into account the current status of the LOREX Project, in this very moment these values can only roughly be determined. The main reason for the latter is that three essential values for the project are not experimentally constrained but calculated, namely: (i) The number of ^{205}Pb atoms that originates from pp-neutrino capture by ^{205}Tl,; (ii) The number of ^{205}Pb atoms that are produced by fast muons of cosmic radiation, and (iii) absolute detection limit δ_a of the SADM method, which should be $\delta_a \leq$ x 10^{-3}

Chemical extraction of Pb from lorandite

Identification of the ^{205}Pb nuclei in the lead sample extracted from the lorandite mineral (Fig.2) requires 10^{-10} to 10^{-11} overall detection sensitivity for $^{205}Pb/Pb$ and a comparable suppression of the ^{205}Tl isobar.
The extraction of lead from pure lorandite should be conducted in two phases: (i) Pilot experiment with a few grams of minerals and (ii) extraction of lead from a few kilograms of minerals.

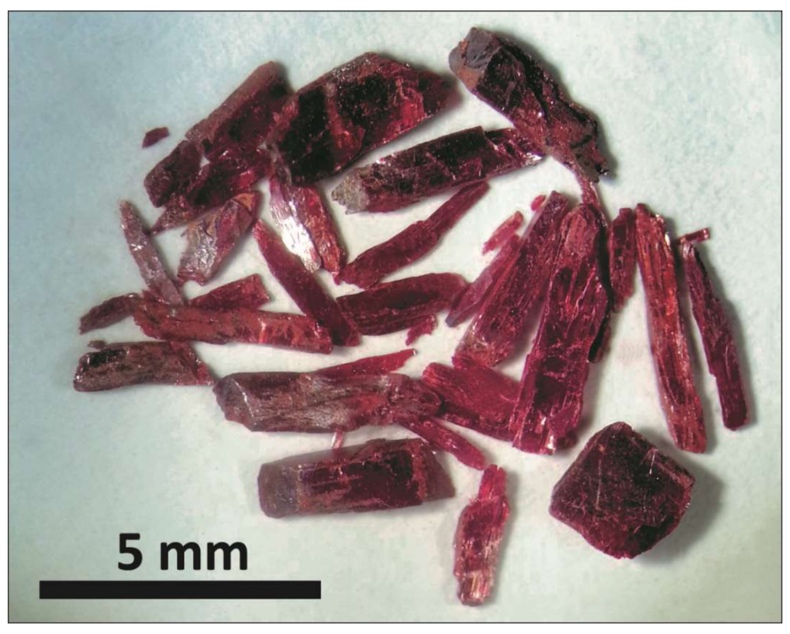

Fig. 2 Lorandite crystals from Crven Dol ore body, Allchar ore deposit.

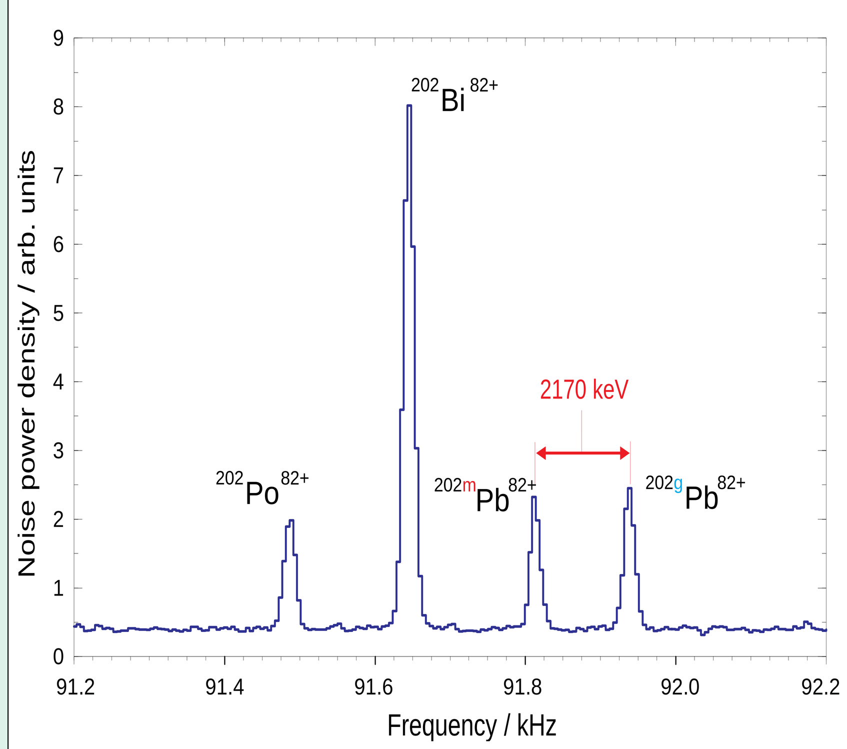

Fig. 3 Schottky frequency spectrum of stored A=202 isobars in the ESR The area of the frequency peaks is directly proportional to the number of stored ions. Here, the peaks of ^{202}Po and ^{202}Pb correspond to single stored ions. Furthermore, two particles of ^{202}Pb indicated as "m" and "g" correspond to the ground and isomeric states.

Motivation and Goals of LOREX

The central goal of the LOREX *LOR*andite *EX*periment [1] is the determination of the long-time average (over ~ 4 MY) of the solar neutrino flux Φ_v with the neutrino-capture reaction [2]:

$$^{205}Tl + \nu_e\ (E_{\nu e} \geq 50 keV) \rightarrow {}^{205}Pb + e^- \quad \dots (1)$$

As was pointed out originally by Freedman [2], the thallium-bearing mineral lorandite, $TlAsS_2$, from the mine of Allchar, Macedonia. The average flux Φ over the exposure time (age of lorandite since its mineralization) follows from the common activation equation, where σ is the solar neutrino capture cross section and λ the decay constant of ^{205}Pb:

$$\Phi_v = N^{-1}\ (T - B)\ (\sigma\varepsilon)^{-1}\lambda\ [1 - \exp(-\lambda a)]^{-1} \quad \dots (2)$$

T – total number of ^{205}Pb atoms ; B – background number of ^{205}Pb atoms [^{205}Tl (μp, n) ^{205}Pb] ; λ – decay constant of ^{205}Pb; **ε** – overall detection efficiency; σ – neutrino capture cross section

This renders finally the mean solar neutrino flux, i.e. *the mean luminosity of the sun during the last 4.3 million years*, the geological age of lorandite.

Determination of the ratio of $^{205}Pb/^{205}Tl$

For the LOREX experiment, a direct detection and counting of the ^{205}Pb atoms was proposed, either with mass-spectrometric methods or with measurements of characteristic atomic transition radiation. The intrinsic limitation of these methods to small sample sizes is substantially helped with an initial chemical Pb-Tl separation, which has been established to provide a separation factor of 10^{13}.
The methods that appear suitable, in principle, for the detection of ^{205}Pb at the trace amount levels under consideration here, are high-energy mass spectrometry (i.e. Accelerator Mass Spectrometry (AMS)) and laser-induced atomic spectroscopy.

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Conclusion:

Taking into account the present-day state-of-the-art of all the techniques needed to solve the four perennial problems of LOREX, we conclude that it is realistic to expect the first result for the solar pp neutrino flux averaged over the last 4.3 million years in the foreseeable future. This number will have most probably still an error margin in the order of 30% or larger, at the 68% CL. We expect, however, that this accuracy could be improved with time, and that it might reach finally a level below ≤ 30% (3).

References:

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