Search for Axions Emitted in Solar pp-Cycle by $^7$Li*


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• Axions
  • Sun as a source of axions (Primakoff effect, thermally excited lines, $^7$Li line)
  • Resonant absorption of axion
• Description of the experiment
• Results
• Further improvements
• Conclusions
Axion:

- hypothetical neutral pseudoscalar particle;
- predicted by Peccei, Quinn, Weinberg and Wilczek to solve the problem of strong CP violation;
- weakly interacts with ordinary matter;
- no \textit{a priori} predictions of mass and coupling (but $m_a \sim 1/f_a$);
- a good candidate for particles of cold dark matter;
- have to be emitted by the solar core.
- can be coupled to hadrons.
Solar axions: continuous part of spectrum
(Primakoff conversion of photon to axion in electric field of a nucleus)
Monoenergetic lines should also exist in the spectrum of solar axions.
The technique was proposed by Moriyama [PRL 75 (1995) 3222]. Other naturally occurring isotopes with low-lying levels deexcitating via M1 transitions are applicable in this technique; for example, $^{83}\text{Kr}$ (9.4 keV).
\(^{57}\text{Fe} ('\text{iron}' \text{ solar axion}) \text{ allows to exclude values of mass of axion between } \sim 14.4 \text{ keV and (best current value) 0.216 keV [T. Namba, PLB 645 (2007) 398]}.\)

Other possibility – non-thermal excitation of source nuclei.

\(^7\text{Li} \text{ is created in } pp\text{-chain (the main energy source of the Sun).}\)
1. Population of the level via electron capture in $^7$Be
2. Emission of a monoenergetic axion
3. Resonant excitation by the axion
4. Emission of a gamma
5. Detection

First experiment: M. Krcmar et al. [PRD 64 (2001) 115016] $(m_a < 32 \text{ keV})$.
Best limit: A.V. Derbin et al. [JETP Lett. 81 (2005) 365] $(m_a < 16 \text{ keV})$. 
Our experiment:

1. Lithium fluoride (LiF) was taken as a target due to:
   a) its high density of Li nuclei in comparison to other Li compounds;
   b) chemical passivity;
   c) non-hygroscopicity.

2. Few samples of LiF (powder of 99.99% purity, single crystal) were placed in two HPGe detectors in Laboratori Nazionali del Gran Sasso (3800 m w.e.).
The best limit on the axion mass was obtained with a powder sample of 243 g measured during 722 h with HPGe detector GSOR.
If we would observe a gamma peak at 478 keV with area $S$, mass of axion would be

$$m_a = 1.55 \times 10^{11} \times \left(\frac{S}{\varepsilon t N_7}\right)^{1/4} \text{ eV}$$

$\varepsilon$ – efficiency of the detector,
$t$ – time of measurement,
$N_7$ – number of $^7\text{Li}$ nuclei in the sample.

$m_a < 13.9 \text{ keV} \ (90\% \ C.L.)$
But the radiopurity of this sample was not good. U/Th activity is ~0.1-0.6 Bq/kg in both the powder samples, whereas the crystal sample is <0.02 Bq/kg.
LiF crystal 224 g

Counts/1 keV

Energy (keV)

Counts/1 keV

Energy (keV)
As the single crystal LiF target is much less contaminated by U/Th daughters than the powder samples, we prepared a new crystal of LiF with mass of ~550 g. It will improve the sensitivity of the next stage of the experiment which is to start soon.
LiF(W) single crystals

Total mass is ~550 g.
Conclusions

1. Search for solar $^7$Li axion was performed in LNGS with LiF targets.
2. No peaks in the region of interest were found.
3. Upper limit on mass of hadronic axion was set: $m_a < 13.9$ keV. It closes the existing window of possible axion masses between the previous experimental limit (of 16.0 keV) and the 14.4 keV energy of the next potential source of quasi-monochromatic solar axions from $^{57}$Fe.
4. The sensitivity of the experiment will be improved by using the massive single crystal LiF target with good radiopurity.