SEARCH FOR AXIOELECTRIC EFFECT OF 5.5 MeV SOLAR AXIONS USING BGO DETECTORS

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<PATRAS 2013 > Mainz, 24-27 июня, 2013

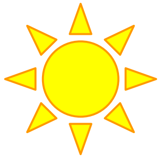
If the axion exists, the Sun is an intense source of these particles.

- *The main solar chain reactions are one of the possible sources of axions. The ^{7}Be electron capture $e^{-}+{}^{7}Be \rightarrow {}^{7}Li^{*}+\nu$ can produce 478 keV axions which are emitted in ^{7}Li M1-transition. The axion flux is proportional to the flux of ^{7}Be-neutrino .*

- *The more intense flux one can expect for 5.5 MeV axions appearing in the **$p(d,{}^{3}He)\gamma$** reaction. The flux of 5.5 axions is directly related to the flux of pp-neutrino ($6 \cdot 10^{10}$ $\nu/cm^{2}c$) and is comparable with axion flux from nuclear reactors or artificial radioactive sources.*

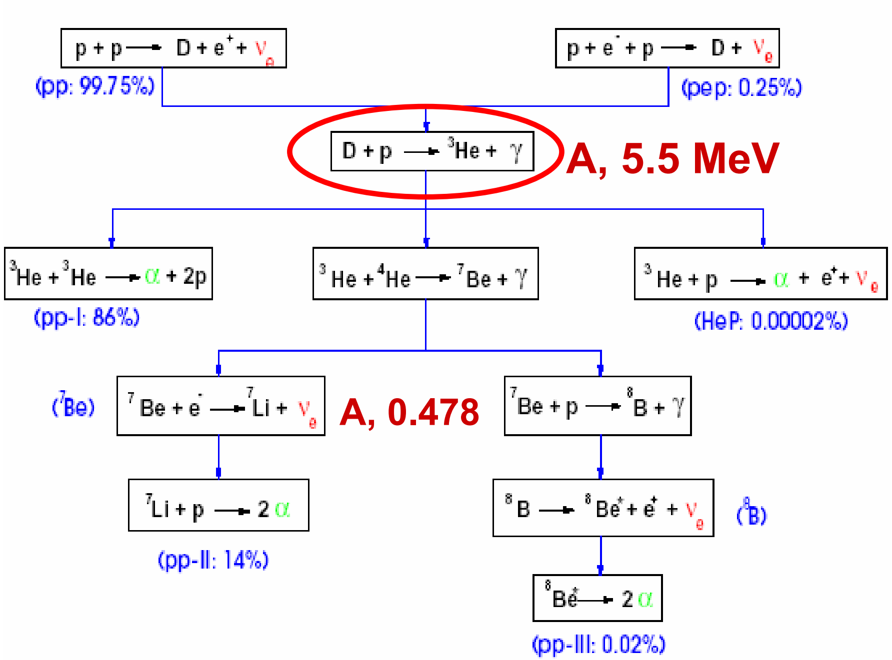
- *To detect the axions we use axioelectric-effect (analog of photo-effect) that has Z^{5} dependence on the cross section.*

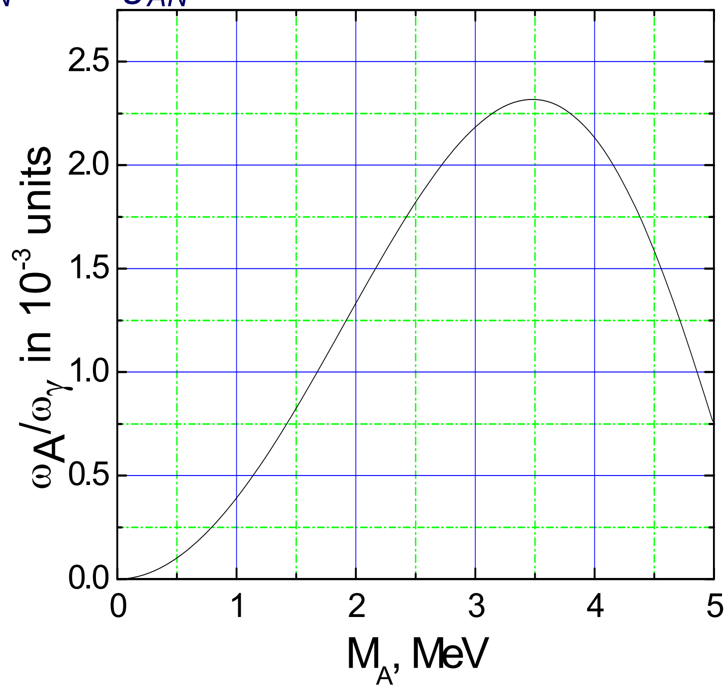
$$p+d \rightarrow {}^{3}He+A \dashrightarrow A + e^{-} + Z \rightarrow Z + e^{-}$$



The flux of the 5.5 MeV axions depends on axion-nucleon coupling constant g_{AN}

If the proton is captured from S-states, that corresponds to M1-transition, the pseudoscalar particle can be emitted instead of γ-quanta. The axion emission probability depends on the axion-nucleon coupling strength which consists of isoscalar and isovector coupling constants g_{AN}^0 and g_{AN}^3.





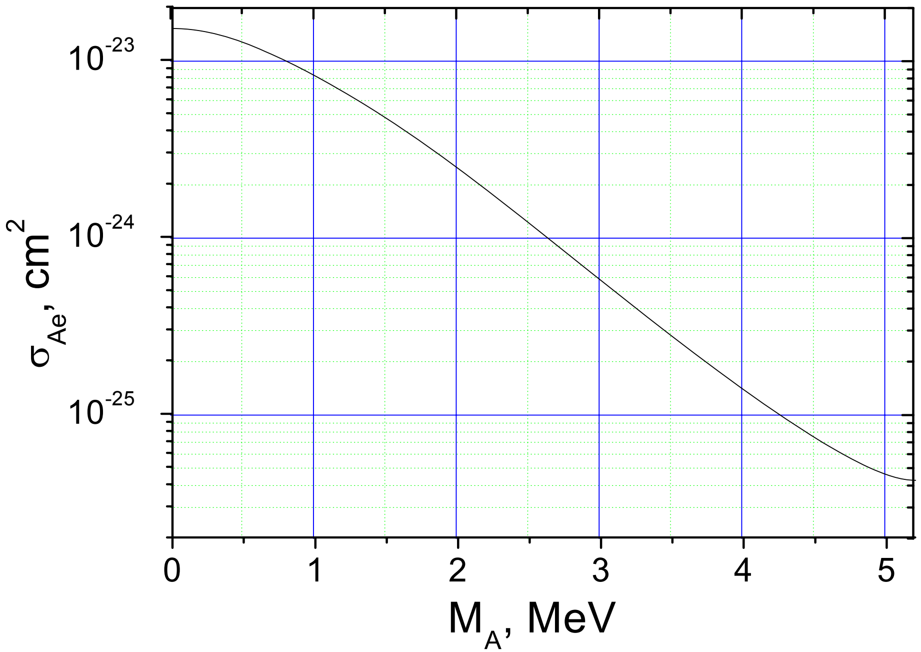
The axion emission probability is:

$$\frac{\omega_A}{\omega_\gamma} = \frac{\chi}{2\pi\alpha}\left[\frac{g_{AN}^3}{\mu_3}\right]^2\left(\frac{p_A}{p_\gamma}\right)^3$$

where p_A and p_γ - is axion and photon moment, χ=0.55 is the probability to be captured from S-state, $\mu_3 = \mu_p - \mu_n$=4.71 is isovector magnetic moment.

The axio-electric effect cross-section depends on axion-electron coupling constant g_{Ae}

The total cross-section for K-shell electrons was calculated by Zhitnitskii and Skovpen:



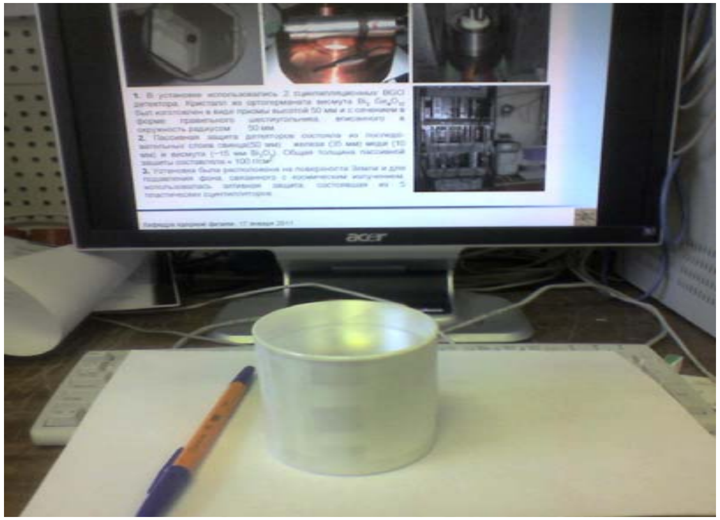
The cross-section vs axion mass for g_{Ae}=1.

$$\sigma_{ae} = 2(Z\alpha m)^5 \frac{g_{Ae}^2}{m^2} \frac{p_e}{p_A} \left\{ \frac{4E_A(E_A^2+m_A^2)}{(p_A^2-p_e^2)^4} - \frac{2E_A}{(p_A^2-p_e^2)^3} - \frac{64}{3} p_e^2 p_A^2 m \frac{m_A^2}{(p_A^2-p_e^2)^6} - \frac{16 m_A^2 p_A^2 E_e}{(p_A^2-p_e^2)^5} - \frac{E_A}{p_e p_A} \frac{1}{(p_A^2-p_e^2)^2} \ln\frac{p_e+p_A}{p_e-p_A} \right\}$$

Since the cross section is proportional **Z^5**, *bismuth atoms* (**Z=83**) *have the maximum cross-section and BGO detector is the most suitable detector to search for the axio-electric absorption.*

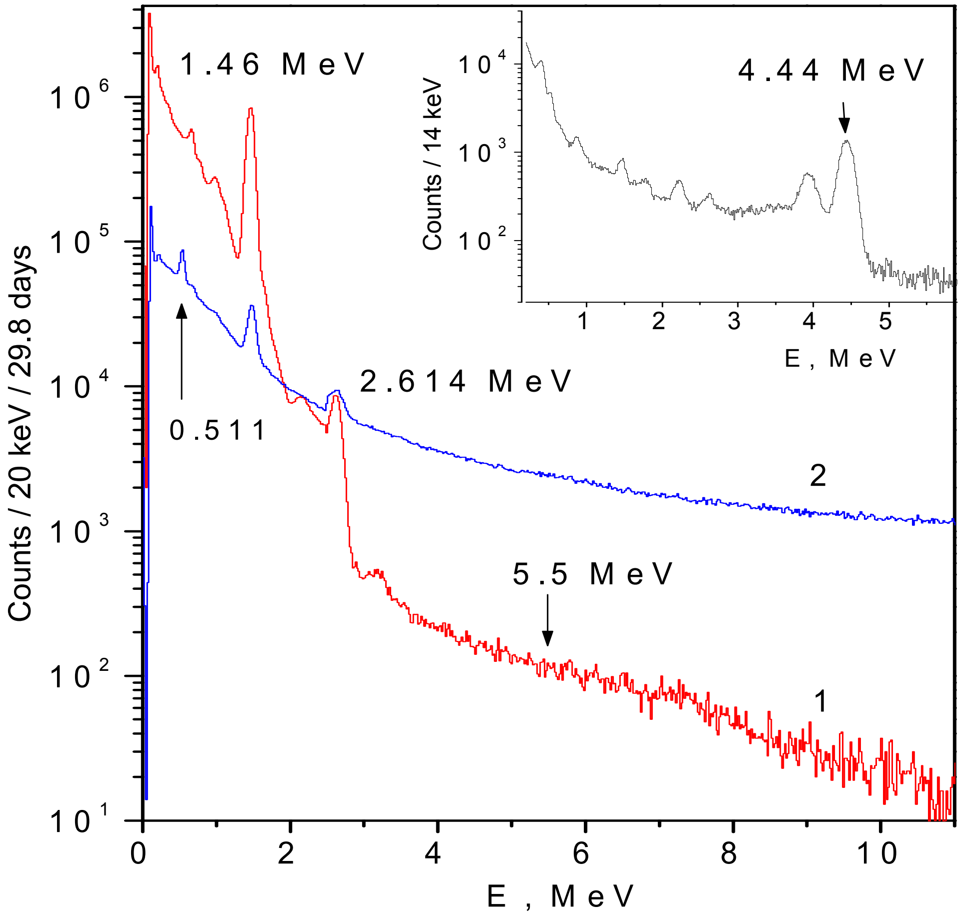
The cross section of axio-electric effect on Bi atom should be in ~ ***$5 \cdot 10^5$ times*** *more than on the atom of carbon, which is basis of most of liquid organic scintillators, and in* ***7300*** *and* ***120*** *times more than on Si and Ge atoms, respectively.*

Experimental setup with BGO detectors



We used a 2.46 kg BGO crystal, manufactured from bismuth orthogermanate $Bi_4Ge_3O_{12}$ (1.65 kg of Bi) to search for the 5.5 MeV axions. The BGO crystal was shaped as a cylinder, 76 mm in diameter and 76 mm in height. Passive shield of the detector consisted of lead layers (100 mm), bismuth (~ 20 mm Bi_2O_3) and copper (10 mm). The total thickness of the passive shielding was ≈ 130 g/cm^2. The setup was located on the Earth's surface. In order to suppress the cosmic–ray background we used an active veto, which consisted of five 50x50x12 cm plastic scintillators.

The BGO spectrum measured during 29.8 days



The energy spectrum of the BGO detector measured (1) in anticoincidence and (2) in coincidence with the muon veto. The position of the expected 5.5 MeV axion peak is denoted by an arrow. In inset the spectrum measured with Pu-Be neutron source is shown.

Two intense peaks with the energies 1.46 MeV and 2.614 MeV are induced by ^{40}K and ^{208}Tl decays. The peaks were used for energy calibration and stability. The dependence of energy resolution of BGO detector vs energy **σ = C · √E** *. The parameter* **C** *was found to be 0.04 Mev$^{1/2}$. The values of* **σ** *determined from the background spectrum are in good agreement with the measurements performed with 60Co and 207Bi standard calibration souses. The expected deviation of the 5.5 MeV peak due to the axion absorption is* **σ = 93 keV.**

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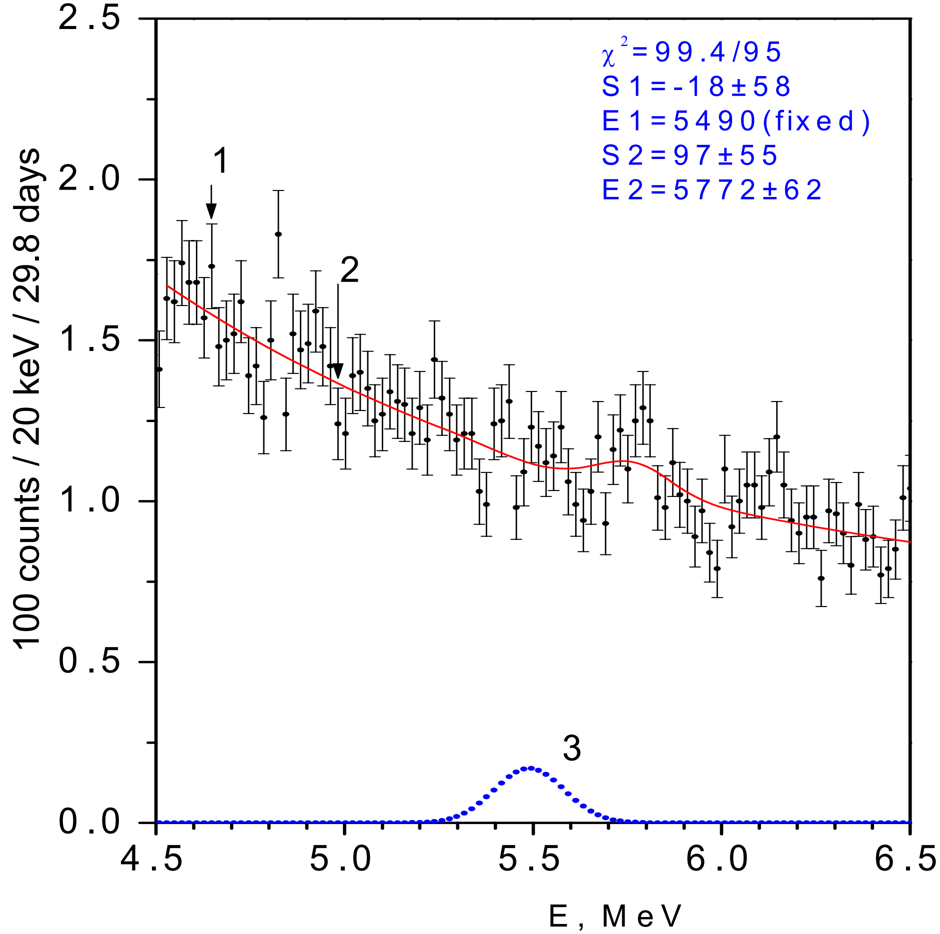
The fit results



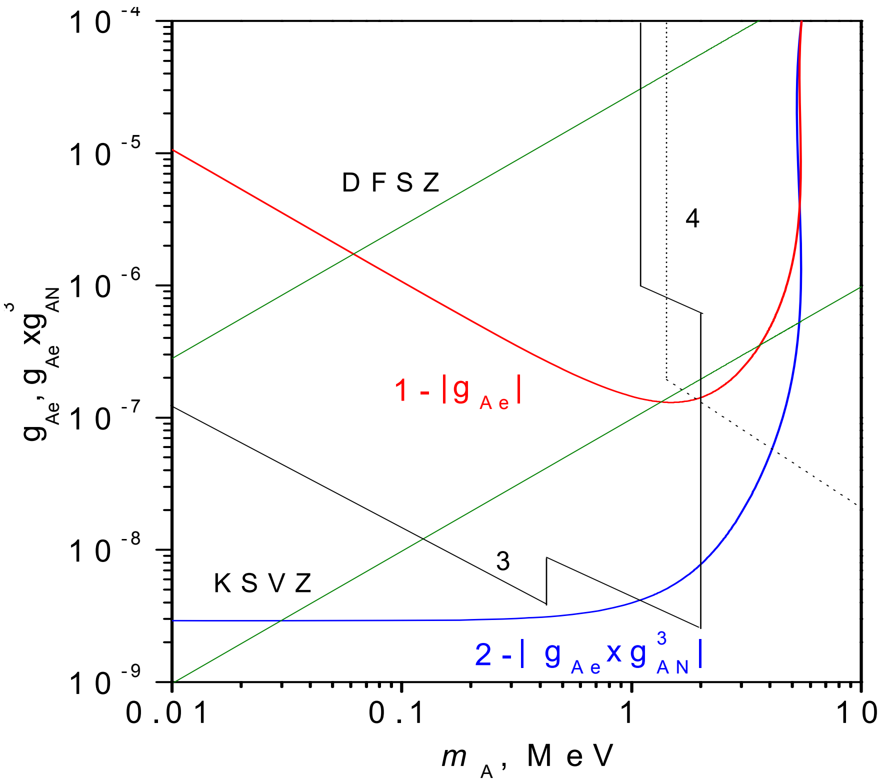
Energy spectrum measured by BGO detector in 4.5 -6.5 MeV interval. The response function of BGO for 5.5 MeV electrons is shown (line 3).

The spectrum measured in the range of (4.5-6.5) MeV was fitted by a sum of exponential and two Gaussian functions:

$$N(E) = a + b \times \exp(cE) + \sum_{i=1}^{2} \frac{S_i}{\sqrt{2\pi\sigma_i}} \exp[-\frac{(E_i - E)^2}{2\sigma_i^2}]$$

Here a, b and c are parameters of the function describing the smooth background. The position and dispersion of the first Gaussian peak corresponded to the desired-peak parameters: E1 = 5.49 MeV is the axion peak position, σ1 = 0.093 MeV is the Gaussian peak standard deviation. Because a small unknown peak can be seen at ~ 5.8 MeV, the second Gaussian was added to the fitting function. The intensity of the 5.49 MeV peak was found to be S1 = 18±58, this corresponds to the upper limit on the number of counts in the peak, S_{lim} = 85 at a 90% confidence level

The limits on g_{Ae} and $g_{Ae} \cdot g_{AN}$ coupling constants



The limits on the g_{Ae} coupling constant obtained by 1- present work, 2 - present work for |gAexg3AN|, 3- solar and reactor experiments (Borexino, Texono), 4- beam dump experiments.

The expected number of events S due to axio-electric absorption is:

$$S = \varepsilon \cdot N_{Bi} \cdot T \cdot \Phi_A \cdot \sigma_{Ae}$$

where ε=0.67-registration efficiency, $N_{Bi}=4.76 \cdot 10^{24}$- number of Bi atoms, $T=2.57 \cdot 10^{6}$ – time of measurement. The axion flux Φ_A is proportional to the constant $(g^3_{AN})^2$ and cross section σ_{Ae} is proportional g_{Ae}^2 . As a result, the value S depends on the product of the axion coupling with the electron and nucleons – $(g_{Ae})^2 \cdot (g^3_{AN})^2$. The relation $S \le S_{lim}$ obtained in the experiment, limits the possible values $|g_{Ae} \cdot g^3_{AN}|$ and m_A as it is shown in figure.

As a result, the new upper limit on **$|g_{Ae} \cdot g^3_{AN}| < 2.9 \cdot 10^{-9}$ (90% c.l.)** at m_A=1 MeV is obtained. In model of the hadronic axion this restriction corresponds to the limit on the hadronic axion-electron coupling **$|g_{Ae}| \le (1.4\text{-}9.7) \cdot 10^{-7}$** for axions with masses $0.1 < m_A < 1$ MeV.