ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
2015. Т. 46. ВЫП. 2

LOOKING FOR ANTINEUTRINO FLUX FROM ^{40}K WITH LARGE LIQUID SCINTILLATOR DETECTOR

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We regard the possibility of detecting the antineutrino flux producing by the ^{40}K placing inside the Earth. Thermal flux of the Earth could be better understood with observing such a flux. Lower and upper limitations on the ^{40}K antineutrino flux are presented.

PACS: 14.60.Lm; 29.40.Mc

INTRODUCTION

Measured Earth thermal flux was estimated as 30–40 TW [1]. This is approximately 60–80 mW/m^2 in average. We do not know exactly all heat sources producing the flux like this. According to Bulk Silicate Earth (BSE) element abundances in the Earth, the amount of radioactive isotopes can explain only about 20 TW of total thermal flux. It is produced by decays of ^{238}U, ^{232}Th and ^{40}K [2, 3]. They regard some exotic thermal sources like natural nuclear reactor placed in the Earth core [4].

Modern neutrino registration methods can give an answer on amount of radioactivity in the Earth. All radioactive elements and georeactor emit antineutrinos, which pass the Earth's thickness and go away in the Cosmos not delaying in it. Large scintillating detector in vicinity of the surface can detect these antineutrinos and obtain total antineutrino flux, which is proportional to the total mass of radioactive elements.

Antineutrino can be detected through the inverse beta-decay reaction (IBD), which produces pair events in the detector clearly recognized in backgrounds. However, it has relatively high threshold of 1.8 MeV, that cuts ^{40}K antineutrinos

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with maximal energy of 1.3 MeV. The ^{40}K antineutrinos can be detected only through elastic scattering on electron reaction, whose cross section is two orders lower than the IBD one.

Geoneutrino flux from ^{238}U and ^{232}Th was detected recently by two scintillation detectors of large volume — KamLAND (1000 t) [5] and Borexino (300 t) [6]. Measured geoneutrino flux does not contradict the minimal abundances of ^{238}U and ^{232}Th followed from Bulk Silicate Earth (BSE), but does not also cut other theories with larger amounts [7, 8]. Experimental uncertainty is about 25%. Georeactor power is limited by 4.5 TW from these measurements.

In [9], they regard geoneutrino flux produced by ^{40}K. If potassium abundance achieves value of 3.76% (from [8]), the flux becomes comparable to the ^{7}Be flux from the Sun: $7.8 \cdot 10^8$ cm$^{-2} \cdot$ s^{-1} contra $4.8 \cdot 10^9$ cm$^{-2} \cdot$ s^{-1} of the ^{7}Be flux.

Potassium abundance in the Earth varies in a number of works from 0.024% [3] up to 3.76% [8]. We analyzed the influence of potassium abundances in the Earth layers on the ^{40}K antineutrino flux and estimated upper and lower limits of potassium flux. In contrast to [3], we placed most part of potassium in the core and observable abundance in the crust. The calculations we did for the detector volume and scintillator are the same as for the Borexino one.

1. THE ^{40}K ANTINEUTRINO FLUX

The ^{40}K decay scheme is shown in Fig. 1 [10, 11]. Main transition with probability of 89.25% goes to base state of ^{40}Ca emitting beta particle and antineutrino with boarder energy 1.311 MeV. In 10.55% of events, there is K capture on existing level of ^{40}Ar with emitting monoenergetic neutrino of 44 keV and then emitting gamma when coming to base state of ^{40}Ar with energy 1.46 MeV. In 0.2%, K capture leads to coming into base state of ^{40}Ar with emitting 1.5 MeV monoenergetic neutrino.

We calculated the ^{40}K antineutrino spectrum corresponding to beta spectrum shown in Fig. 2 [3, 12]. Our beta spectrum differs from the experimental one, but can be used for estimation effect in a detector of antineutrino. At first approximation, one does not need to use weak magnetism corrections for antineutrino

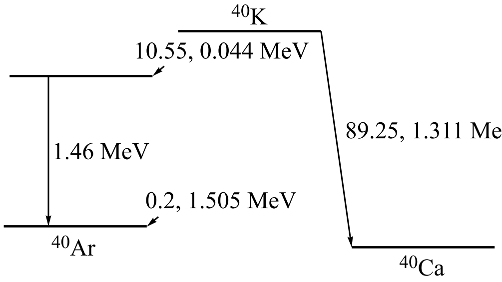

Fig. 1. Decay scheme of ^{40}K

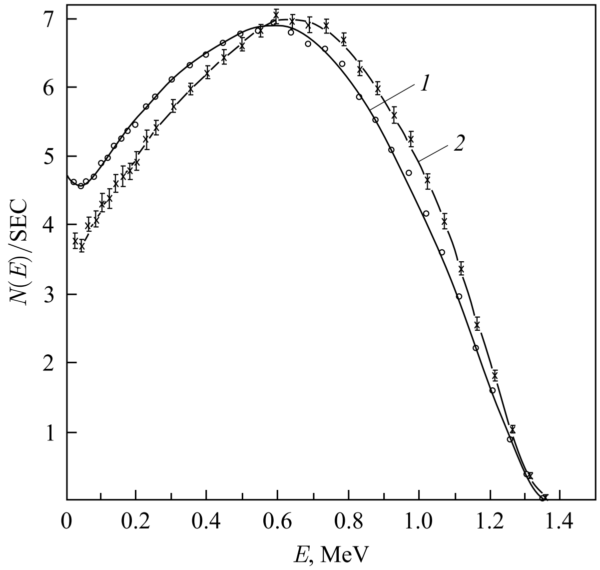

Fig. 2. Beta spectra for ^{40}K: *1* — experimental measurement including background; *2* — beta spectrum after subtracting background and corrected on detector response function

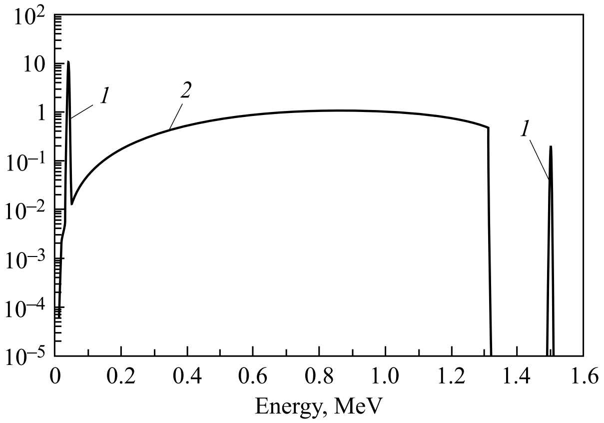

Fig. 3. Neutrino spectrum from ^{40}K according to decay scheme shown in Fig. 1 (*1* — neutrinos, *2* — antineutrinos); Y-axis shows probability of producing (anti)neutrino per MeV per one decay of ^{40}K

spectrum that are large enough for beta particles but small for antineutrinos. That is why we do not use any corrections for antineutrino spectrum, they are shown in Fig. 3.

2. NEUTRINO DETECTOR

We regard as detector target liquid organic scintillator. In Borexino detector, they use scintillator on the base of Pseudocumene (PC), but in KamLAND detector — on the base of mineral oil. In some modern detectors, they propose to use scintillator on the base of Linear Alkyl Benzene (LAB). In Table 1, we show numbers of carbon, hydrogen and electrons containing in 1000 t of LAB and PC.

Table 1. **Abundance of H, C and electrons in 1000 t of linear alkyl benzene and pseudocumene**

1000 t	LAB	PC
Formulae	$C_{18}H_{30}$	C_9H_{12}
H	$7.465 \cdot 10^{31}$	$6.013 \cdot 10^{31}$
C	$4.479 \cdot 10^{31}$	$4.510 \cdot 10^{31}$
Electrons	$3.434 \cdot 10^{32}$	$3.307 \cdot 10^{32}$

Antineutrinos from ^{40}K are registered through the reaction of elastic scattering of antineutrinos on target electrons

$$\bar{\nu}_e + e^- \to \bar{\nu}'_e + e^{-\prime}. \qquad (1)$$

Cross section of reaction (1) is written as

$$\frac{d\sigma^W}{dT} = g_F^2 \frac{m}{\pi}\left[(1+2x^2)^2\left(1-\frac{T}{E}\right)^2 + 4x^2 - 2x^2(1+2x^2)\frac{mT}{E^2}\right], \qquad (2)$$

where E and T are antineutrino energy and electron recoil energy, correspondingly, $g_F^2 \frac{m}{\pi} = 4.308 \cdot 10^{-45}$ cm^2, $x^2 = \sin^2\theta_W = 0.232$.

3. EARTH MODELS TESTING

To do calculations, we have chosen the Earth model like concentric spheres according to seismic data. From the surface down to Mohorovicic's boarder there is the crust, which is divided into upper, middle and lower parts. We took data on the depth of parts from [13], where data are presented with step 2 degrees on altitude and longitude. Then, down to 660 km we accounted there is an upper mantle, which we also accounted as lithosphere. At the depth of 2900 km lower mantle is changing to outer core (liquid one), which lasts until 5140 km, then down to the Earth centre continues inner (solid) core.

We placed ^{40}K in the crust and upper mantle only when calculated lower antineutrino flux limit. We took potassium abundance as 2.1% weight for the

Table 2. **Potassium abundance in Earth's layers (in weight %). To change on g/g units, one needs to use coefficient** 10^{-2}

Earth layer	Min. abund., %	Max. abund. (Model 1), %	Max. abund. (Model 2), %
Crust	2.1	2.1	2.1
Upper mantle	2.1	2.1	3.0
Lower mantle	0.0	0.0	3.5
Outer core	0.0	10.0	4.5
Inner core	0.0	10.0	6.0
Oceans	0.042	0.042	0.042
Sediments	0.2	0.2	0.2
Total	0.36	3.74	3.74

Table 3. **Antineutrino and neutrino fluxes and effect in 100 t of pseudocumene**

Flux and rate	Neutrino	Antineutrino	Neutrino	Antineutrino
Flux, $\mathrm{cm}^{-2}\cdot\mathrm{s}^{-1}$	$1.70\cdot10^{6}$	$7.58\cdot10^{8}$	$3.05\cdot10^{5}$	$1.36\cdot10^{8}$
Rate, d^{-1}	0.06	4.04 (Mod.1) 4.54 (Mod.2)	0.015	1.01

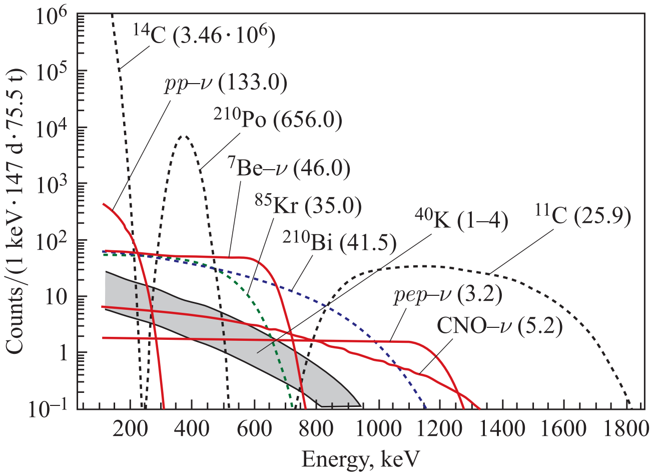

Fig. 4. Single-event spectra in energy scale of Borexino per 147 days of data taking in 75.5 t of liquid scintillator [15]. The corridor for possible values of the ^{40}K antineutrino flux single-event spectrum is shown

crust and upper mantle according to [14] (mean value appeared to be 0.3%). When counting upper limit, we add potassium also in solid and liquid cores in amount to achieve 3.7% for the whole Earth according to Hydridic Earth (HE) model [7, 8]. Data we used are shown in Table 2.

In Table 3, one can find calculated antineutrino and neutrino fluxes from ^{40}K and expected effects for the target of 100 t of pseudocumene with threshold 200 keV. Vacuum oscillations were taken into account when doing calculations but not the MSW effect. Muon and taon neutrinos appeared in oscillations do the input in the effect of scattering.

Recoil electron spectra for minimal and maximal potassium abundances are shown in Fig. 4 in comparison with single events from solar neutrino fluxes and inner backgrounds of Borexino detector [15]. Daily counting rate is shown in round brackets. Counting rate for the flux from the ^{7}Be solar neutrino flux is 46 per day and the ^{40}K antineutrino flux rate is from 1 to 4 per day.

CONCLUSION

We present calculations of recoil electron spectra produced by antineutrino flux from isotope ^{40}K placed in inner parts of the Earth. It appears that the ^{40}K antineutrino flux is comparable with neutrino flux produced by ^{7}Be in solar flux measured by Borexino. This background is never regarded as sufficient for solar neutrino detectors. Calculations show that it can achieve 10% of beryllium neutrinos effect depending on potassium abundance in the Earth.

The result of our estimation does not contradict the Borexino experimental data even in case of maximal abundance according to [7, 8].

Detector of Borexino type could register the ^{40}K antineutrino spectrum and establish the upper limit on potassium abundance in the Earth. In the nearest plans of Borexino Collaboration is to take efforts in decreasing the existing background level to lower levels. This definitely increases the probability of determining the ^{40}K antineutrino flux. Detection of extra amount of ^{40}K can find additional heat source for the Earth thermal flux.

The work was supported by RFBR grants 12-02-12124 and 12-02-92440.

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