Solar neutrino capture cross-section for ^{76}Ge nuclei

Almaz Fazliakhmetov[1,2], Lev Inzhechik[1], Grigory Koroteev[1], Yury Lutostansky[3], Victor Tikhonov[3], Andrey Vyborov[1,2]

[1]Moscow Institute of Physics and Technology, Russia;
[2]Institute of Nuclear Research, Russian Academy of Sciences; [3]National Research center "Kurchatov Institute", Russia

Introduction

In the experiments of GERDA and LEGEND studying the double beta decay of the ^{76}Ge isotope, the total energy of the beta-electrons is measured. The absorption of solar neutrinos by the ^{76}Ge nucleus as a result of successive reactions

$$\nu_{e\ solar} + {}^{76}_{32}Ge \rightarrow {}^{76}_{33}As^{*} + e^{-}$$

$$ {}^{76}_{32}As \rightarrow {}^{76}_{34}Se^{*} + e^{-} + \bar{\nu}_e \qquad (*)$$

induces background events indistinguishable from the studied beta decay. In this paper, the neutrino capture rate was calculated from the formula :

$$R = \int_0^{\infty} \rho_{solar}(E_\nu)\,\sigma_{total}(E_\nu)\,\mathrm{d}E_\nu \qquad (**)$$

The peculiarity of this work composed in taking into account the transitions to both discrete and continuous (resonant) states of the daughter nucleus (fig. 1).

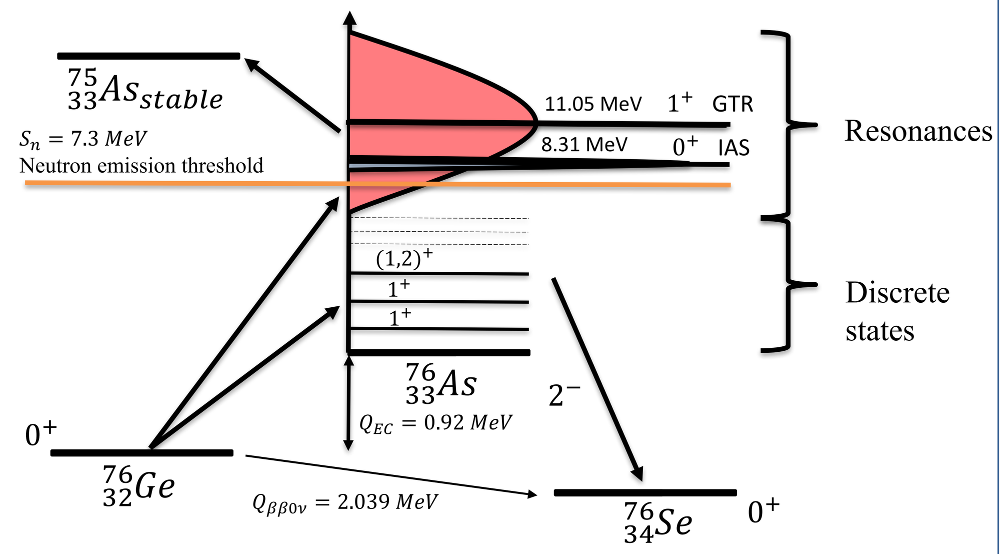

Fig. 1. Scheme of transition

Solar neutrino spectrum

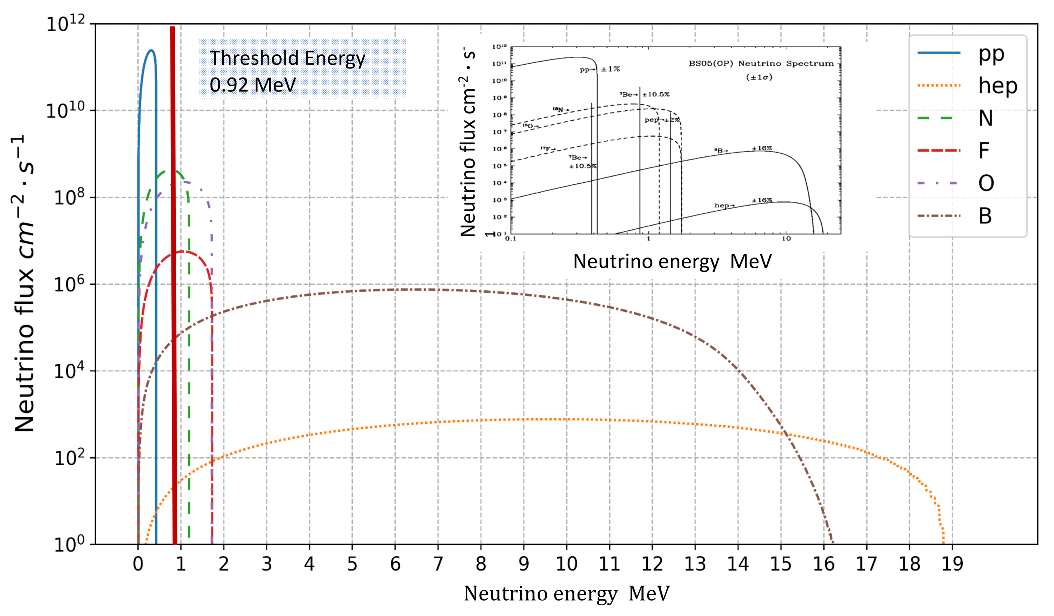

Fig. 2. Solar neutrino spectrum

The spectrum of solar neutrinos, figured in the formula (**), was taken from BS05(OP) model **[1].** The greatest contribution to the capture rate is made by boron neutrinos.

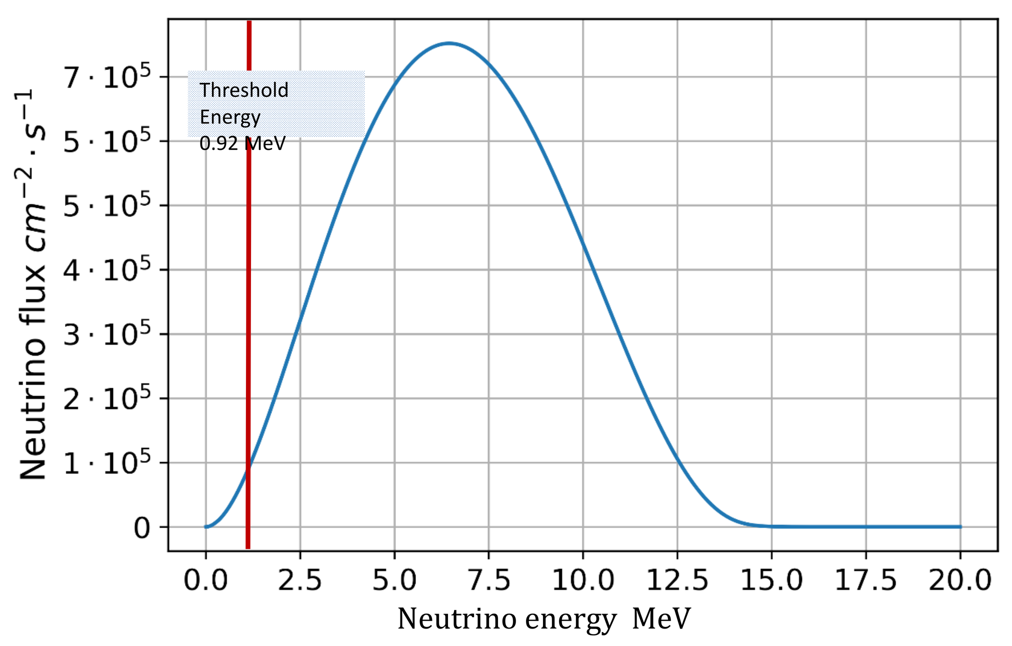

Fig. 3. Spectrum of boron neutrino

Cross-section calculations

To calculate the neutrino capture cross-section both discrete and continuous (resonant) states of the ^{76}As nucleus were considered.

$$\sigma_{total}(E_\upsilon) = \sigma_{discrete}(E_\upsilon) + \sigma_{res}(E_\upsilon)$$

$$(\sigma_{total}(E_\upsilon) = 0,\ if\ E_\upsilon \le Q)$$

$$\sigma_{discrete}(E_\upsilon) = \sum_k \frac{G_F^2 cos^2\theta_c}{\pi} p_e E_e F(Z, E_e)\left[B(F)_k + \left(\frac{g_A}{g_V}\right)^2 B(GT)_k\right] \ \textbf{[2]}$$

$$\sigma_{res}(E_\nu) = \int_0^{\min(E_\nu - Q;\ Esep)} \frac{G_F^2 cos^2\theta_c}{\pi} p_e E_e F(Z, E_e) S_\beta(E)\, dE$$

G_F – the weak coupling constant
θ_c – the Cabibo angle
p_e/E_e – the outgoing electron momentum / total energy
$E_e = E_\upsilon - Q - E + m_e \qquad p_e = \sqrt{E_e^2 - m_e^2}$
E – excitation energy of ^{76}As
$F(Z, E_e)$ – the Fermi function **[3]**
$\frac{g_A}{g_V} = 1.267$ **[4]** $\qquad Q = Q_{EC}(^{76}As)$
$B(F)_k, B(GT)_k$ – the Fermi (Gamow-Teller) response of the k-th excited state of ${}^{76}_{33}As^{*}$ **[5]**
$S_\beta(E)$ – nuclear beta strenght function
E_{sep} = 7.3 MeV – neutron separation energy

The strength function describing the probability of transition to one or another excited state takes into account the contribution of both resonances (isobaric analog and giant Gamow-Teller **[6]**):

$$S_\beta(E) = \left(\frac{g_A}{g_V}\right)^2 \cdot S_\beta(E)_{\text{GTR}} + S_\beta(E)_{\text{IAS}}$$

This work was done on the assumption that at excitation energies of the ^{76}As nucleus above E_{sep}, neutron emission takes place with the formation of a stable nucleus of ^{75}As isotope (fig. 1), so such transitions to states with energies higher than E_{sep}, were not considered.

Fig. 4 presents the spectrum of the ^{76}As nucleus excitation energy, which repeats the shape of the experimental strength function **[5].** The narrow IAS peak lies above E_{sep} and therefore the IAS does not contribute to the total capture cross section. The calculation took only the tail of the GTR (Gaussian distribution) , lying below the level of E_{sep} (on the graph it is marked with a dashed line).

The strength function for the GTR was normalized according to the sum rule:

$$\int_0^{\infty} S_\beta(E)_{\text{GTR}}\, dE = 3(N - Z) = 36$$

Cross-section calculations

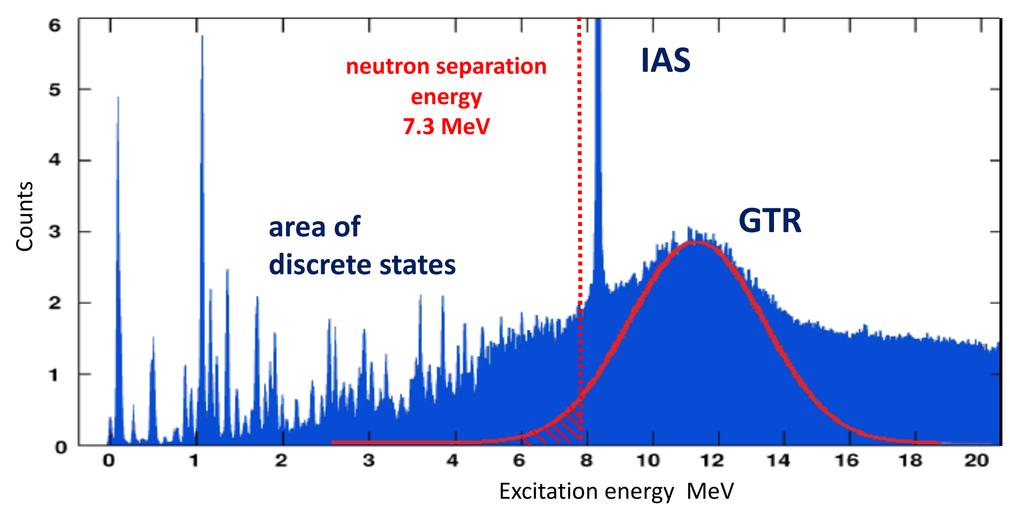

Fig. 4. Excitation-energy spectra for the Ge(He,t)As reaction for $0^0 < \theta < 0.5^0$ **[5]**

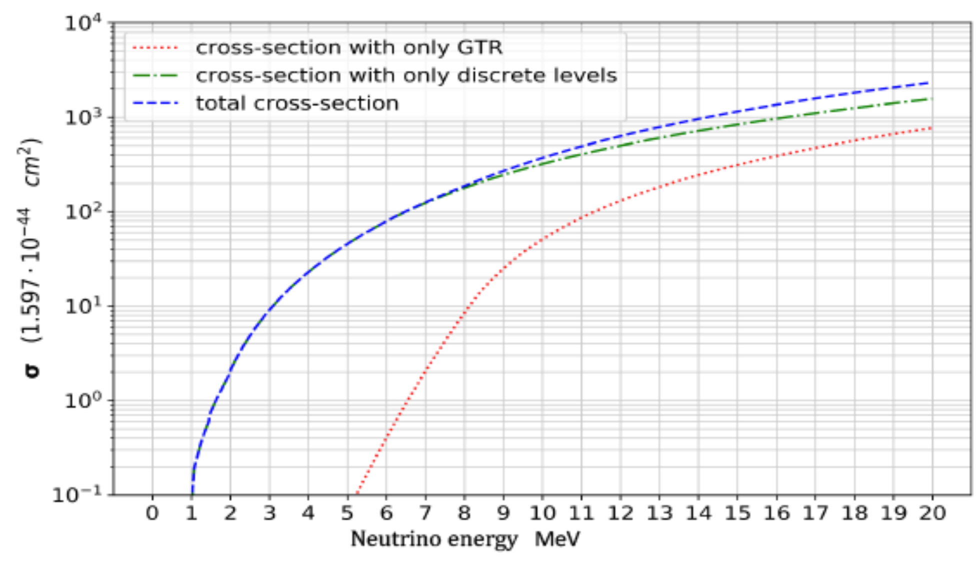

Fig. 5. Cross-section of neutrino capture

The dependence of the capture cross-sections on the incident solar neutrino energy is shown in the Fig. 5. The contribution of continuous states to the total cross section becomes noticeable from approximately 9 MeV.

Conclusion

In the present work the contribution of the Gamow-Teller resonance below the neutron separation energy was considered. It increased the estimation of the neutrino capture rate by the ^{76}Ge nucleus by 10% as compared with **[2]**. On the next stage it is proposed to estimate the contribution of the resonance states above E_{sep} requiring further development of the theory. In addition, it is planned to study the process (*) as a solar neutrino background for the GERDA and LEGEND experiment taking into account the real geometry of the detectors.

Rate of solar neutrino capture (in SNU)	pep	hep	N	F	O	B	total
only discrete states	1.369	0.0451	0.102	0.021	0.828	13.54	15.9
discrete states and GTR	1.369	0.0568	0.102	0.021	0.828	15.22	17.59
GTR contribution	0%	20%	0%	0%	0%	11%	9.6%

Table 1. Rate of solar neutrino.

Contact

Andrey Vyborov
MIPT, INR RAS
Email: vyborov94@gmail.com
Phone: +7 (968) 628-13-73

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