Improving the value of the neutrino absorption cross-section on gallium and prospects of short-baseline experiments for studying neutrino oscillations.

Vladislav Barinov
### Gallium Anomaly

<table>
<thead>
<tr>
<th></th>
<th>SAGE $^{51}$Cr</th>
<th>SAGE $^{37}$Ar</th>
<th>GALLEX $^{51}$Cr 1</th>
<th>GALLEX $^{51}$Cr 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Активность, кКи</td>
<td>516.6 ± 6.0</td>
<td>409 ± 2</td>
<td>1714$^{+30}_{-43}$</td>
<td>1868$^{+89}_{-57}$</td>
</tr>
<tr>
<td>$p_{ном}$, атомов $^{71}$Ge/сут</td>
<td>14.0 ± 1.5 ± 0.8</td>
<td>11.0$^{+1.0}_{-0.9}$ ± 0.6</td>
<td>11.9 ± 1.1 ± 0.7</td>
<td>10.7 ± 1.2 ± 0.7</td>
</tr>
<tr>
<td>Масса Ga (т)</td>
<td>13.1 (метал.)</td>
<td>13.1 (метал.)</td>
<td>30.4 (GaCl$_3$:HCl)</td>
<td>30.4 (GaCl$_3$:HCl)</td>
</tr>
<tr>
<td>$R = p_{ном}/p_{теоp}$</td>
<td>0.95 ± 0.12</td>
<td>0.79 ± 0.10</td>
<td>0.953 ± 0.11</td>
<td>0.812 ± 0.11</td>
</tr>
</tbody>
</table>

Allowed regions of oscillations parameters with combining SAGE + GALLEX

Full statistical uncertainty of the experiment BEST: $\pm 4.5\%$ – for each zone
$\pm 3.7\%$ – all target

Theoretical uncertainty $+3.6\% - 2.8\%$
Absorption Cross Section

\[ \nu_e + ^{71}\text{Ga} \rightarrow e^- + ^{71}\text{Ge} \]

\[ \sigma = \sigma_0 \langle \omega_e^2 G(Z, \omega_e) \rangle \]

\[ \sigma_0 = \frac{4\pi^3 \ln 2 \alpha \hbar^3}{m_e^3 c^4} \left( \frac{2I_f + 1}{2I_i + 1} \right) \frac{Z}{ft_{1/2}(I_f \rightarrow I_i)} \]

Scale factor for the cross section value

\[ ft_{1/2}(I_f \rightarrow I_i) = \frac{2\pi^3 \ln 2 \hbar^7}{m_e^5 c^4} \frac{1}{(G_V^2 |M_{i,f}|_F^2 + G_A^2 |M_{i,f}|_{GT}^2)} \]

ft – value

\[ \langle \omega_e^2 G(Z, \omega_e) \rangle = \frac{1}{2\pi \alpha Z} \int_{\omega_e, \text{min}}^{\omega_e, \text{max}} \omega_e p_e F(Z, \omega_e) \phi(q_{\nu}) d\omega_e \]

The dimensionless phase space factor, averaged by electron energies
The scheme of the decay of $^{71}\text{Ga}$ and the spectra of artificial sources

\[
\begin{array}{ccc}
3/2^- & B(GT)_{500} & 0.500 \text{ MeV} \\
5/2^- & B(GT)_{175} & 0.175 \text{ MeV} \\
1/2^- & B(GT)_{\text{g.s.}} & \\
\end{array}
\]

Spectrum of $^{51}\text{Cr}$

<table>
<thead>
<tr>
<th>$E_\nu$ (MeV)</th>
<th>Относительные доли</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.752</td>
<td>8.49 (1) %</td>
</tr>
<tr>
<td>0.747</td>
<td>81.63 (1) %</td>
</tr>
<tr>
<td>0.432</td>
<td>0.93 (1) %</td>
</tr>
<tr>
<td>0.427</td>
<td>8.95 (1) %</td>
</tr>
</tbody>
</table>

Spectrum of $^{37}\text{Ar}$

<table>
<thead>
<tr>
<th>$E_\nu$ (MeV)</th>
<th>Относительные доли</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.813</td>
<td>9.80 (1) %</td>
</tr>
<tr>
<td>0.811</td>
<td>90.20 (1) %</td>
</tr>
</tbody>
</table>
Calculations

\[ Q = 233.5 \pm 1.2 \text{ keV} \quad \text{Frekers} \]
\[ Q = 232.69 \pm 0.15 \text{ keV} \quad \text{Old} \]

\[ T_{1/2}^{(71\text{Ge})} = 11.43 \pm 0.03 \text{ d} \]

\[ \log f t_{1/2}^{(71\text{Ge})} = 4.353 \pm 0.005 \]

\[ B(GT)\text{g.s.} = 0.086 \pm 0.001 \]

\[ \sigma_0 = (8.6 \pm 0.1) \times 10^{-46} \text{ cm}^2 \]

\[ \sigma_0^{\text{Bahcall}} = (8.611 \pm 0.011) \times 10^{-46} \text{ cm}^2 \]

Matrix elements of the transitions and the results of calculations

<table>
<thead>
<tr>
<th>$E_x$($^{71}$Ge) [keV]</th>
<th>$J^\pi$</th>
<th>$\frac{d\sigma}{d\Omega}$ (q = 0) [mb/sr]</th>
<th>GT %</th>
<th>$B$(GT) $\times 10^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>g.s. $\frac{1}{2}-$</td>
<td>0.786(9)</td>
<td>92</td>
<td>8.52(11) $^a$</td>
<td></td>
</tr>
<tr>
<td>175 $\frac{5}{2}-$</td>
<td>0.071(4)</td>
<td>40</td>
<td>0.34(26)</td>
<td></td>
</tr>
<tr>
<td>500 $\frac{3}{2}-$</td>
<td>0.171(4)</td>
<td>87</td>
<td>1.76(14)</td>
<td></td>
</tr>
<tr>
<td>708 $\frac{3}{2}-$</td>
<td>0.018(1)</td>
<td>55</td>
<td>0.11(5)</td>
<td></td>
</tr>
<tr>
<td>808 $\frac{1}{2}-$</td>
<td>0.210(4)</td>
<td>92</td>
<td>2.29(10)</td>
<td></td>
</tr>
<tr>
<td>1096 $\frac{3}{2}-$</td>
<td>0.184(4)</td>
<td>84</td>
<td>1.83(17)</td>
<td></td>
</tr>
</tbody>
</table>

\[
\sigma = \sigma_{g.s.}\left[1 + \lambda_{175}\frac{B(GT)_{175}}{B(GT)_{g.s.}} + \lambda_{500}\frac{B(GT)_{500}}{B(GT)_{g.s.}}\right]
\]

\[
\sigma^{(51}\text{Cr}) = (59.20 \pm 1.14) \times 10^{-46} \text{ cm}^2
\]

\[
\sigma^{(37}\text{Ar}) = (71.5 \pm 1.5) \times 10^{-46} \text{ cm}^2
\]

\[
\sigma^{(51}\text{Cr}) = (59.2 \pm 1.1) \times 10^{-46} \text{ cm}^2
\]

\[
\sigma^{(37}\text{Ar}) = (71.5 \pm 1.4) \times 10^{-46} \text{ cm}^2
\]

C. Giunti


Absorption Cross Section for $^{65}$Zn

<table>
<thead>
<tr>
<th>$E_\nu$ (МэВ)</th>
<th>Относительные доли</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.352</td>
<td>48.35 (11) %</td>
</tr>
<tr>
<td>0.236</td>
<td>50.23 (11) %</td>
</tr>
</tbody>
</table>

$$\sigma(^{65}\text{Zn}) = (94.3 \pm 2.1) \times 10^{-46}\text{ см}^2$$

$$\sigma = \sigma_{g.s.} \left[ 1 + \frac{\sum E_x \lambda_{E_x} B(GT)_{E_x}}{B(GT)_{g.s.}} \right]$$

$$\lambda_{175} = 0.7969, \lambda_{500} = 0.4789, \lambda_{708} = 0.3146, \lambda_{808} = 0.2466, \lambda_{1096} = 0.0934$$
Uncertainties

The relative uncertainty of the cross sections obtained during the work is 2\% for the 51Cr and 37Ar sources, and 2.2\% for the 65Zn source. The results obtained for 51Cr and 37Ar agree with that presented in [3].

Taking into account the refined value of the neutrino absorption cross section in gallium obtained in this paper, the resulting error of the BEST experiment using the 51Cr source will be 4.9\% for each of the bands and 4.17\% for the total target, instead of 5.5\% and 4.8\%, respectively.

If a 65Zn source is used in the BEST experiment, the resulting error is 5.0\% for each of the zones and 4.3\% for the full target, respectively.
Sensitivity Contours

![Sensitivity Contours Diagram](image-url)
Conclusions

- Refined values of the neutrino absorption cross sections for gallium for $^{51}\text{Cr}$ and $^{37}\text{Ar}$ sources are obtained, and it is shown that, despite the consideration of all the uncertainties in the cross section, the results will change insignificantly. A value of the absorption cross section for $^{65}\text{Zn}$ was separately obtained and a formula was obtained with the calculated relative phase space factors.

- Obtained updated areas of allowed oscillation parameters for combining SAGE + GALLEX + BEST.

- It is also shown in the paper that the main results presented in [1] remain true and there are no more uncertainties in the cross section for the absorption of neutrinos by gallium, which could eliminate the discrepancy between the SAGE and GALLEX experiments.
Acknowledgments

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Thank you for your attention!