Neutrinos Electro-Weak interactions and Symmetries (NEWS) colloquium

The gallium anomaly and its relation to nuclear matrix elements

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This work is inspired by
Prof. Emeritus Hiro Ejiri (RCNP

DBD Related works by our group

- Phys. Rev. Lett. 2016… 48Ca large-scale shell model calc
- Phys. Rev. C 2020… 48Ca λ mechanism
- Phys. Rev. C 2023. … 124Sn nonclosure
- Frontiers Astron. Space Sci. 2021 **(invited)**. … 82Se left-right symmetric model
- Universe2023 **(invited)** … 48Ca Short Range Correlation (UCOM etc)
- arXiv:2406.13417 (Phys. Rev. C, submitted) …. 136Xe nonclosure

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- With J. Terasaki Phys. Rev. C 2019…. 136Xe 130Te QRPA for paring
- With J. Terasaki, EPJ Plus 2021… comparison on models

Open problem in physics

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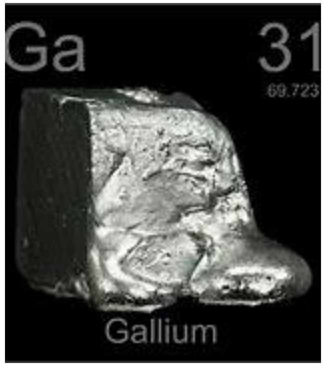
- The gallium anomaly: The measurements of the charged-current capture rate of neutrinos on Ga from strong radioactive sources have yielded results below those expected, based on the known strength of the principal transition supplemented by theory.[39]



Outlines

Nature of Gallium Anomaly and Brief History

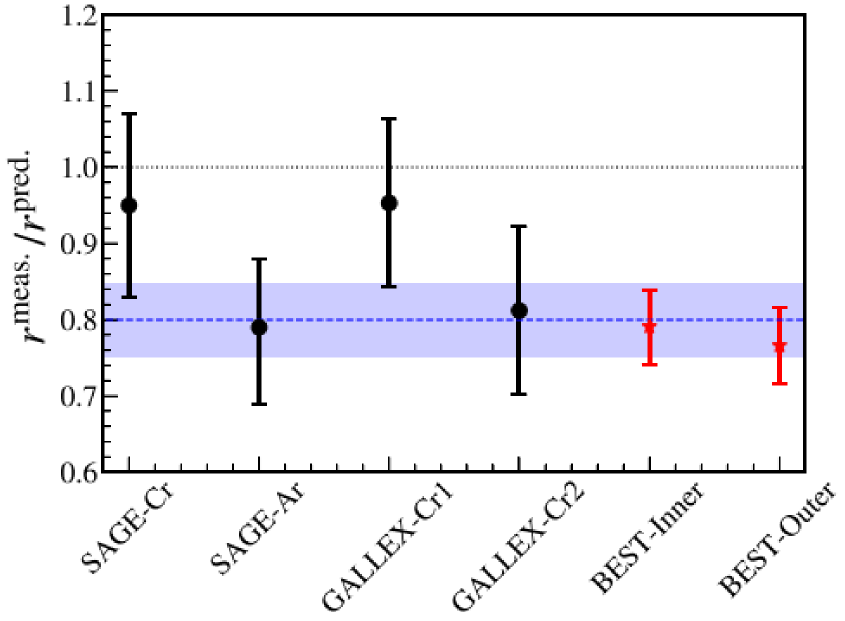
GALLEX, SAGE, and BEST Experiments on Gallium Anomaly

Role of Nuclear Matrix Elements and Cross Sections Calculation on Gallium Anomaly

Shell model calculation for Nuclear Matrix Elements of ^{71}Ga and ^{69}Ga

Summary

[Review article] Elliot, Gavrin, Haxton
Prog. Part. Nucl. Phys. 134 (2024) 104082



The ratio of the measured 71Ge production rate to the predicted rate for all 6 measurements.

The dotted blue line (shading) is the best fit (uncertainty) to all 6 results.

$$\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$$

Nature of Gallium Anomaly

Observation: The gallium anomaly refers to the **unexpected shortfall** in the number of neutrinos detected by gallium-based detectors compared to theoretical predictions.

The key reaction used in the Gallium experiment is the neutrino capture reaction on gallium-71

$$\nu_e + {}^{71}\mathrm{Ga} \rightarrow 71\mathrm{Ge} + e^-$$

The electron neutrino from the Sun or artificial sources (like chromium-51 in calibration runs) interacts with the gallium nucleus.

Key Experiments: Detectors like GALLEX and SAGE observed about 20-25% fewer neutrinos than expected when exposed to neutrino sources.

Potential Explanation: The anomaly may suggest the existence of sterile neutrinos, a type of neutrino that doesn't interact via the weak force, making them undetectable by standard methods.

Theoretical Considerations: Discrepancies in nuclear matrix elements, cross-section calculations, or beta decay rates could also contribute to the anomaly.

Significance: The gallium anomaly raises the possibility of new physics beyond the Standard Model, prompting further experimental and theoretical research.

Brief History Gallium Anomaly

1970s-1980s: Concept Development

The idea of using gallium as a detector material for neutrinos was proposed to study solar neutrinos, leveraging the reaction

$$\nu_e + {}^{71}\mathrm{Ga} \to {}^{71}\mathrm{Ge} + e^-.$$

1990s: Initial Experiments

- **GALLEX (1991-1997):** The first gallium experiment in Italy's Gran Sasso Laboratory detected solar neutrinos but found a significant deficit compared to theoretical predictions.

- **SAGE (1989-Present):** A similar experiment in Russia's Baksan Neutrino Observatory also detected fewer neutrinos than expected, consistent with GALLEX's results.

2000s: Investigation and Hypotheses

- **Sterile Neutrino Hypothesis:** The observed deficit led to speculation that neutrinos might be oscillating into undetectable sterile neutrinos, potentially explaining the anomaly.
  … Note that the existence of a sterile neutrino with a mass of about one-five-hundredth of an electron's own has been rejected by other experiments (Nature 2023). But the results from BEST actually put the sterile neutrino's mass higher than that.

- **Cross-Section and Nuclear Matrix Element Analysis:** Researchers re-examined cross-sections and nuclear matrix elements used in predictions to determine if theoretical errors could explain the anomaly.

Brief History Gallium Anomaly Cont…

2010s: Continued Research and New Experiments

- **Re-evaluation of Theoretical Models:** Ongoing scrutiny of nuclear models and potential experimental errors continued, but the anomaly persisted.

- **Introduction of BEST Experiment (2018-2021):** The Baksan Experiment on Sterile Transitions (BEST) was conducted to specifically test the sterile neutrino hypothesis, confirming the anomaly with a dual-chamber approach that detected fewer neutrinos than predicted.

2020s: Current Status

- **Increased Interest in Sterile Neutrinos:** The persistence of the anomaly across different experiments has strengthened the case for sterile neutrinos or other new physics.

- **Ongoing Theoretical and Experimental Efforts:** The gallium anomaly remains a focus of intense study, with ongoing efforts to either confirm sterile neutrinos or find alternative explanations.

GALLEX (Gallium Experiment, Italy)

https://gallery.lngs.infn.it/en/gallery/past-experiment/gallex_gno/

GALLEX or Gallium Experiment was a radiochemical neutrino detection experiment that ran between 1991 and 1997 at the Laboratori Nazionali del Gran Sasso (LNGS)

The key reaction used in the **GALLEX** experiment is the **neutrino capture reaction** on gallium-71

$$\nu_e + {}^{71}\mathrm{Ga} \rightarrow 71\mathrm{Ge} + e^-$$

The electron neutrino from the Sun or artificial sources (like chromium-51 in calibration runs) interacts with the gallium nucleus.

Observations From GALLEX on Gallium Anomaly

- GALLEX detected fewer neutrinos than expected, observing about 60-70% of the predicted neutrino flux from the Sun, revealing a significant deficit.
- GALLEX used artificial neutrino sources (e.g., chromium-51) to test the detector's accuracy. The results showed a similar deficit in detected neutrinos, reinforcing the observed anomaly.
- The deficit was consistent across multiple measurement campaigns and detector calibrations, ruling out temporary or one-time experimental errors.

SAGE (Soviet-American Gallium Experiment, Russia)

SAGE was devised to measure the radio-chemical solar neutrino flux based on

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

Gallium–Germanium Neutrino Telescope main room (Wikipedia)

The target for the reaction was 50-57 tonnes of liquid gallium metal stored deep (2100 meters) underground at the Baksan Neutrino Observatory in the Caucasus Mountains in Russia

Key Observations From SAGE on Gallium Anomaly

- SAGE detected significantly fewer solar neutrinos than predicted, observing about 60-70% of the expected flux, consistent with findings from the GALLEX experiment.
- The use of chromium-51 as an artificial neutrino source yielded similar results, further confirming the observed shortfall in neutrino interactions.
- The observed deficit led to the suggestion that neutrinos might be oscillating into undetectable states (possibly sterile neutrinos), which could explain the lower detection rates.

BEST (Baksan Experiment on Sterile Transitions, Russia)

In 2014, the SAGE-experiment's GGNT-apparatus (gallium-germanium neutrino telescope) was upgraded to perform a very-short-baseline neutrino oscillation experiment BEST (Baksan Experiment on Sterile Transitions) with an intense artificial neutrino source based on ^{51}Cr.

Main hall of GGNT with the assembled BEST setup.

https://www.appec.org/news/best-baksan-experiment-on-sterile-transitions

Key Observations from BEST on Gallium Anomaly

- In June 2022, the BEST experiment released two papers observing a 20-24% deficit in the production the isotope germanium expected from the reaction $\nu_e + {}^{71}\mathrm{Ga} \rightarrow 71\mathrm{Ge} + e^-$ confirming previous results from SAGE and GALLEX on the so called "gallium anomaly" pointing out that a sterile neutrino explanation can be consistent with the data [*Physical Review Letters*. **128** (23): 232501]

- The experiment utilized a dual-chamber setup, allowing for independent measurements of neutrino interactions, enhancing the reliability of the results and reducing systematic errors.

- Further work have refined the precision for the cross section of the neutrino capture in 2023 which was proposed as a possible inaccuracy source back in 1998

- BEST results provided additional confirmation of the half-life of ^{71}Ge (approximately 11.43 days), which is crucial for understanding the dynamics of neutrino detection in gallium experiments. [Physical Review C. 109 (5): 055501]

Potential Explanations of Gallium Anomaly

1) Neutrino Oscillations to Sterile Neutrinos

Some theories propose the existence of a fourth type of neutrino, the **sterile neutrino**, which interacts even more weakly than the three known neutrino flavors. Sterile neutrinos do not interact via the weak force and thus cannot be detected in typical neutrino detectors. If electron neutrinos are oscillating into sterile neutrinos, it could explain the lower-than-expected detection rates.

2) Uncertainty in Gallium Cross Section

The detection of neutrinos in gallium-based experiments relies on the interaction of neutrinos with gallium atoms, specifically via the reaction: $\nu_e + {}^{71}\mathrm{Ga} \rightarrow 71\mathrm{Ge} + e^-$. The rate of this reaction depends on the precise cross section for neutrino capture by gallium. If the theoretical value of the cross section is off, it could explain the observed discrepancy in neutrino flux measurements.

3) Nuclear Matrix Element Uncertainties

Inaccuracies in the calculations of nuclear matrix elements, which determine the probability of transitions during neutrino interactions, may contribute to the observed anomalies.

4) Experimental Systematics

Systematic errors or uncertainties in the measurement techniques of gallium-based experiments, including detector efficiency, background noise, and calibration processes, could affect the observed neutrino capture rates.

Importance of Nuclear Matrix Elements (NME) on Ga Anomaly

The charged-current weak reaction that is central to the gallium anomaly is:

$$\nu_e + {}^{71}\mathrm{Ga} \rightarrow 71\mathrm{Ge} + e^-$$

Probability of such interactions (the cross section) is highly dependent on the NME.

The cross section for neutrino capture is directly proportional to the square of the nuclear matrix element. This means that any uncertainty or inaccuracy in the NME leads to errors in the predicted neutrino capture rate, and therefore in the number of neutrinos detected.

Required Gamow–Teller (GT) transition strength for neutrino capture cross section can be written as

$$B_{GT}(p,n) = \frac{1}{2j_i + 1}\left|\left\langle f \left|\left| M^{(p,n)} \right|\right| i \right\rangle\right|^2$$

Where nuclear matrix element $M^{(p,n)}$ can be written as

$$M^{(p,n)} = M_{GT} + \delta M_T \qquad \delta \approx 0.1 \qquad M_{GT} = \langle f||O_{GT}||i\rangle = \left\langle f \left|\left| \sigma\tau^{\pm} \right|\right| i \right\rangle$$

$$M_T = \langle f||O_T||i\rangle = \left\langle f \left|\left| [\sigma \times Y_2]_L \tau^{\pm} \right|\right| i \right\rangle$$

L=1,2,3 (rank of tensor operator)

Y_2 is spherical Harmonics of rank 2

How nuclear matrix elements M_{GT} and M_T are calculated in Nuclear Shell Model are discussed next

GT Type NME Calculations Using Nuclear Shell Model

The GT type NME is written as

$$M_{GT} = \langle f||O_{GT}||i\rangle = \left\langle f\left|\left|\sigma\tau^{\pm}\right|\right| i\right\rangle = \sum_{k_1' k_2'} \mathrm{OBTD}(fik_1'k_1\lambda)\langle k_1' \left|\left|\sigma\tau^{\pm}\right|\right| k_1\rangle$$

- $|i\rangle$ is the ground state of initial nucleus ^{71}Ga having the spin-parity $J_i^{\pi} = \frac{3}{2}^{-}$
- $|f\rangle$ is the ground and excited states of final nucleus ^{71}Ge having the spin-parity $J_f^{\pi} = \frac{1}{2}^{-}, \frac{5}{2}^{-}, \frac{3}{2}^{-}$
- k_1 and k_1' represents (n, l, j) quantum numbers for nuclear orbits

One body transition density (OBTD)

$$\mathrm{OBTD}(fik_1'k_1\lambda) = \frac{\langle f|\left|\left[a_{k_1'}^{+} \otimes \tilde{a}_{k_1}\right]_{\lambda}\right||i\rangle}{\sqrt{2\lambda+1}}$$

$a's$ are creation and annihilation operators, λ is the rank of transition operator

One Body Matrix Elements (OBME)

$$\left\langle k_1' \left|\left|\sigma\tau^{\pm}\right|\right| k_1\right\rangle = 2(-1)^{l_1'+j_1'+3/2}\sqrt{(2j_1'+1)(2j_1+1)}\begin{Bmatrix} 1/2 & 1/2 & 1 \\ j_1 & j_1' & l_1' \end{Bmatrix} \times \langle s||\vec{s}||s\rangle \delta_{l_1' l_1} \delta_{n_1' n_1}$$

{} represents 6j symbol

OBTD can be calculated in nuclear model like Shell model and OBME are calculated manually with simple programming

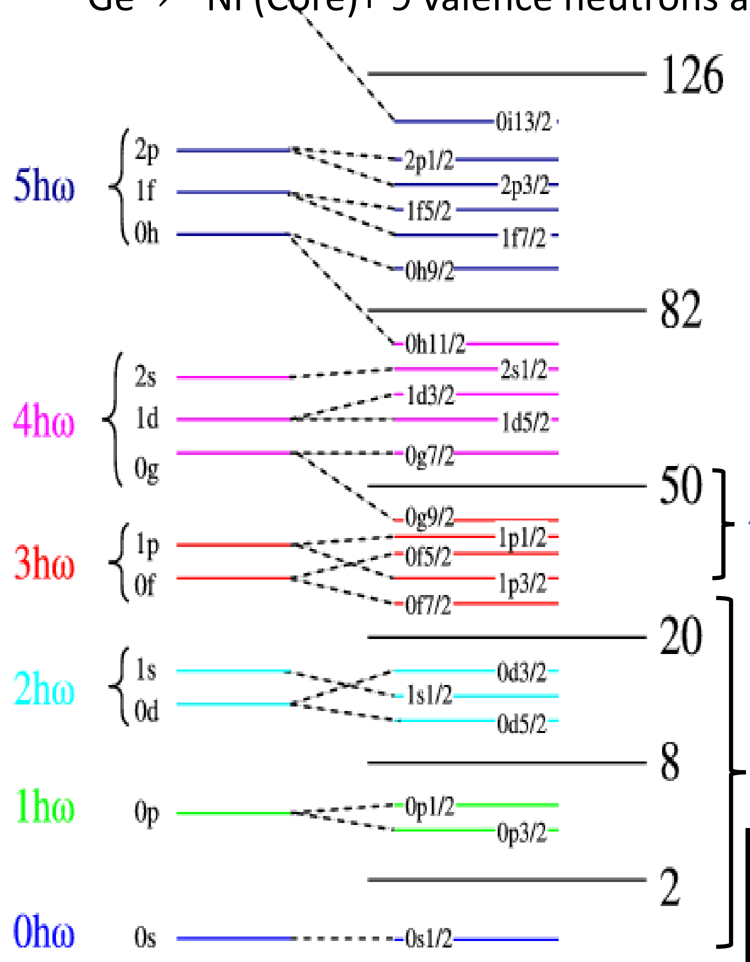
OBTD Calculations with Nuclear Shell Model

$^{71}Ga \rightarrow {}^{56}Ni$ (Core)+ 12 valence neutrons and 3 valence protons

$^{71}Ge \rightarrow {}^{56}Ni$ (Core)+ 11 valence neutrons and 4 valence protons

$^{69}Ga \rightarrow {}^{56}Ni$ (Core)+ 10 valence neutrons and 3 valence protons

$^{69}Ge \rightarrow {}^{56}Ni$ (Core)+ 9 valence neutrons and 4 valence protons



Nuclear Shell structure

jj44-valence space: $0g_{9/2}$, $1p_{1/2}$, $0f_{5/2}$, $1p_{3/2}$

ORBITS

^{56}**Ni Core**

Valence protons and neutrons occupy the above orbits of jj44-model space

Snapshot of JUN45 Hamiltonian of jj44 Model Space

jun45 - Notepad

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```
! M. Honma et al., PRC80, 064323 (2009)
!#JUN45  1=p3/2 2=f5/2 3=p1/2 4=g9/2 (A/58)^-0.3
! relabel for jj44 model space
!-999  -9.8280   -8.7087   -7.8388   -6.2617 56. 58. 0.3
!#JUN45   1=f5/2 2=p3/2 3=p1/2 4=g9/2 (A/58)^-0.3
 -999  -8.7087  -9.8280   -7.8388   -6.2617 56. 58. 0.3
  2  2  2  2   1  0  -1.06840
  2  2  2  2   3  0  -2.04450
  2  2  2  1   1  0   0.08610
  2  2  2  1   3  0   0.40400
  2  2  2  3   1  0   1.60460
  2  2  1  1   1  0   0.13540
  2  2  1  1   3  0   0.00690
  2  2  1  3   3  0   0.03530
  2  2  3  3   1  0   0.58830
  2  2  4  4   1  0   0.57230
  2  2  4  4   3  0   0.43170
  2  1  2  1   1  0  -1.91180
  2  1  2  1   2  0  -1.31830
  2  1  2  1   3  0  -0.69740
  2  1  2  1   4  0  -1.57650
  2  1  2  3   1  0  -0.60390
  2  1  2  3   2  0  -0.45510
  2  1  1  1   1  0   0.44940
  2  1  1  1   3  0   0.37250
```

OBTD are calculated with determined Eigen states using shell model code KSHELL

Results For GT Type NME Calculations

NME Type	Initial Spin-Parity (J_i^π)	Final Spin Parity (J_f^π)	NME Value
$\langle f \| \vec{\sigma}\tau^{\pm} \| i \rangle$	$\frac{3}{2}^-$ of ^{71}Ga	$\frac{1}{2}^-$ of ^{71}Ge	-0.7909
$\langle f \| \vec{\sigma}\tau^{\pm} \| i \rangle$	$\frac{3}{2}^-$ of ^{71}Ga	$\frac{5}{2}^-$ of ^{71}Ge	-0.1452
$\langle f \| \vec{\sigma}\tau^{\pm} \| i \rangle$	$\frac{3}{2}^-$ of ^{71}Ga	$\frac{3}{2}^-$ of ^{71}Ge	0.0957

Matches with Existing Results with Shell Model

State	$\langle f \| O_{GT} \| i \rangle$
$1/2^-_{g.s.}$	−0.795
$5/2^-_1$	0.144
$3/2^-_1$	0.100
$3/2^-_2$	0.430
$1/2^-_2$	−0.620

J. Kostensalo et al., PLB 795, 542-547, (2019)

Tensor Type NME Calculations Using Nuclear Shell Model

The Tensor type NME is written as

$$M_T = \langle f||O_T||i\rangle = \left\langle f\left|\left|[\sigma \times Y_2]_L \tau^{\pm}\right|\right| i\right\rangle = \sum_{k_1' k_2'} \mathrm{OBTD}(fik_1'k_1\lambda)\langle k_1'\left|\left|[\sigma \times Y_2]_L \tau^{\pm}\right|\right| k_1\rangle$$

- $|i\rangle$ is the ground state of initial nucleus ^{71}Ga having the spin-parity $J_i^{\pi} = \frac{3}{2}^-$
- $|f\rangle$ is the ground and excited states of final nucleus ^{71}Ge having the spin-parity $J_f^{\pi} = \frac{1}{2}^-, \frac{5}{2}^-, \frac{3}{2}^-$
- k_1 and k_1' represents (n, l, j) quantum numbers for nuclear orbits

One body transition density (OBTD)

$$\mathrm{OBTD}(fik_1'k_1\lambda) = \frac{\langle f|\left|\left[a_{k_1'}^{+} \otimes \tilde{a}_{k_1}\right]_{\lambda}\right||i\rangle}{\sqrt{2\lambda+1}}$$

One Body Matrix Elements (OBME)

$$\left\langle k_1'\left|\left|[\sigma \times Y_2]_L \tau^{\pm}\right|\right| k_1\right\rangle = \langle n_1', l_1', s_1', j_1'||[\sigma \times Y_2]_L \tau^{\pm}||n_1, l_1, s_1, j_1\rangle$$

$$= \sqrt{(2j_1'+1)(2j_1+1)(2L+1)} \begin{Bmatrix} l_1' & s_1' & j_1' \\ l_1 & s_1 & j_1 \\ 2 & 1 & L \end{Bmatrix} \langle l_1'||Y_2||l_1\rangle\langle s_1'||\sigma||s_1\rangle$$

Here we have used the Angular Momentum Algebra Formula

$$\langle (j_a j_b)J||W^r||(j_c j_d)J'\rangle = \sqrt{(2J+1)(2r+1)(2J'+1)}\langle j_a||T^p||j_c\rangle\langle j_b||U^q \mid j_d\rangle \begin{Bmatrix} j_a & j_b & J \\ j_c & j_d & J' \\ p & q & r \end{Bmatrix}$$

Where $W^r = T_r^p \times U_r^q$

Tensor Type NME Calculations Using Nuclear Shell Model

Spherical Harmonics

Further the angular matrix element of spherical harmonics is written as

$$\langle l_1' \| Y_2 \| l_1 \rangle = -(1)^{l_1'} \sqrt{\frac{(2l_1' + 1)(2 * 2 + 1)(2l_1 + 1)}{4\pi}} \begin{pmatrix} l_1' & 2 & l_1 \\ 0 & 0 & 0 \end{pmatrix}$$

Spin-Part

Spin part can be written as

$$\langle s_1' || \vec{s} || s_1 \rangle = \frac{1}{2} \langle 1/2 || \vec{\sigma} || 1/2 \rangle = \sqrt{6}/2$$

With the Above Approach One can calculate OBME and the OBTD Calculated with Shell Model Will Determine the Tensor Type NME

Results For Tensor Type NME Calculations of ^{71}Ga

Our Results of Tensor NME of 71Ga

State	$\langle f \| O_T \| i \rangle$
3/2- to 1/2 - (gs)	0.235
3/2- to 5/2 -	-1.110
3/2- to 3/2 – (1)	0.127
3/2- to 3/2 – (2)	
3/2- to 1/2 – (2)	

Existing Results

Table 1
Results for ^{71}Ga with $\delta = 0.097$ and cc
ements.

State	$\langle f \| O_{GT} \| i \rangle$	$\langle f \| O_{L=2} \| i \rangle$
$1/2^-_{g.s.}$	−0.795	0.521
$5/2^-_1$	0.144	−0.763
$3/2^-_1$	0.100	0.0687
$3/2^-_2$	0.430	0.155
$1/2^-_2$	−0.620	0.353

from Corrigendum to "The Gallium Anomaly Revisited" [J. Kostensalo et al., PLB 795, 542-547, (2019)]

Results of W.C. Haxton [Physics Letters B 431 1998 110–118]

- These are old results which may be quite different from the recent results of Corrigendum to "The Gallium Anomaly Revisited" [Phys. Lett. B 795 (2019) 542–547]

Table 3
Large-basis shell model results for ^{71}Ga → ^{71}Ge Gamow-Teller and spin-tensor matrix elements and the corresponding BGT predictions. The (p,n) BGT calculation was done for δ = 0.097

Transition	$\langle f \| O_{GT} \| i \rangle$	$\langle f \| O_{L=2} \| i \rangle$	BGT^{SM}_{β}	$BGT^{SM}_{(p,n)}$
$3/2^- \to 1/2^-$ (0 keV)	−0.451	0.348	0.051	0.044
$3/2^- \to 5/2^-$ (175 keV)	0.082	−2.23	0.017	0.0045
$3/2^- \to 3/2^-$ (500 keV)	0.056	0.104	0.0008	0.0011

We are looking into the source of differences arising with recent shell model calculations results

Results For Tensor Type NME Calculations of ^{69}Ga

Our Results of Tensor NME of 69Ga

State	$\langle f \| O_T \| i \rangle$
3/2- to 5/2 - (gs)	-0.918
3/2- to 1/2 -	0.318
3/2- to 3/2 – (1)	0.185

Existing Results

Corrected Results of 69Ga from Corrigendum to "The Gallium Anomaly Revisited" [Phys. Lett. B 795 (2019) 542–547]

Table 2
Results for ^{69}Ga with $\delta = 0.097$ and corrected tensor matrix elements.

State	$\langle f\|\|O_{GT}\|\|i\rangle$	$\langle f\|\|O_{L=2}\|\|i\rangle$	$BGT^{SM}{}_{\beta}$	$BGT^{SM}{}_{(p,n)}$
$5/2^-_{g.s.}$	−0.0139	−0.934	4.802×10^{-5}	2.730×10^{-3}
$1/2^-_1$	−0.592	0.318	0.0876	0.0787
$3/2^-_1$	0.0298	0.218	2.220×10^{-4}	6.488×10^{-4}

Although results for 3/2- to 1/2- transition matched with existing shell model calculations, other results are little bit different from existing shell model calculations. We are also looking into it.

Comparison of Different Cross Sections Calculations

Table 5.1
A summary of the published neutrino reaction cross section estimates for $^{71}Ga(\nu_e, e^-)^{71}Ge$ in units of 10^{-45} cm^2. The value for Q_{EC} used in each calculation is shown. All results are given at 68% C.L. See text for details.

Author	Year	$\sigma(^{51}Cr)$	$\sigma(^{37}Ar)$	$Q_{EC}(^{71}Ge)$ (keV)
Bahcall [57]	1997	$5.81^{+0.21}_{-0.16}$	$7.00^{+0.49}_{-0.21}$	232.69(15)
Haxton [44]	1998	6.39 ± 0.68	–	232.69(15)
Barinov et al. [80]	2018	5.91 ± 0.11	7.14 ± 0.15	233.5(1.2)
Kostensalo et al. [83]	2019	5.67 ± 0.06	6.80 ± 0.08	232.49(22)
Semenov [84]	2020	5.94 ± 0.12	7.17 ± 0.15	232.44(9)
Elliott et al. [3]	2023	$5.69^{+0.28}_{-0.06}$	$6.85^{+0.35}_{-0.08}$	232.44(9)

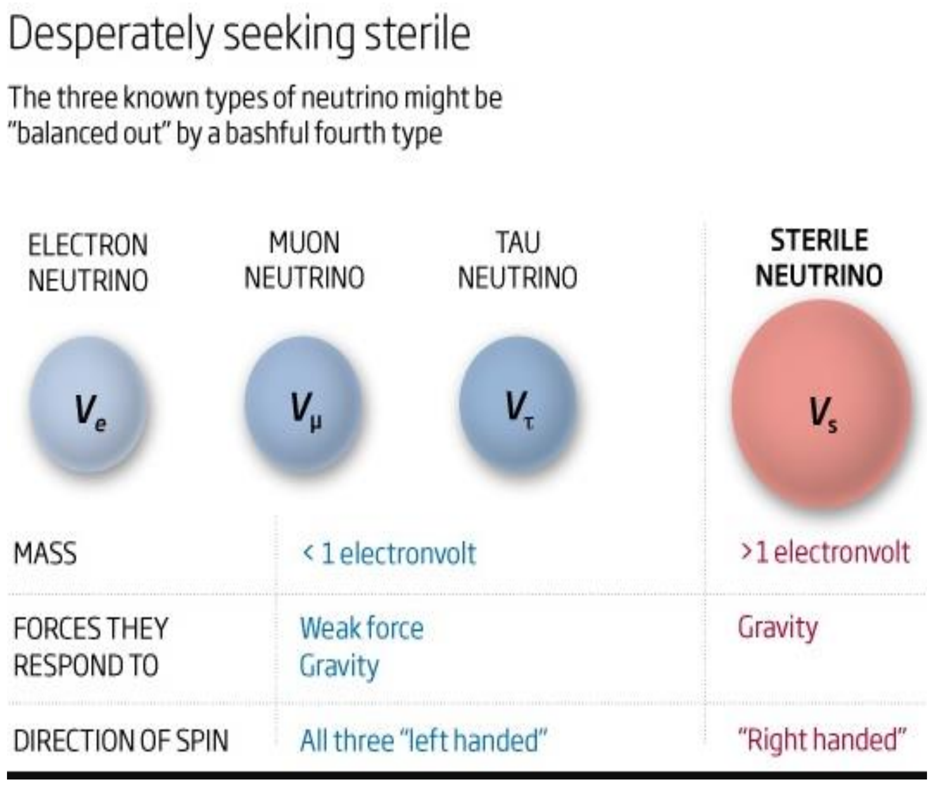
- Taken From S.R. Elliott et al., The gallium anomaly, Progress in Particle and Nuclear Physics Volume 134, January 2024, 104082

- It summarizes the published neutrino reaction cross-section estimates for the reaction: $\nu_e + {}^{71}Ga \rightarrow$ $71Ge + e^-$. These estimates are provided for two different neutrino sources: **chromium-51** and **argon-37Ar**

- This table serves as a comparison of different theoretical and experimental estimates of neutrino cross sections, essential for understanding neutrino interactions and calibrating neutrino detectors like those involved in gallium experiments (GALLEX, SAGE, BEST).

Sterile Neutrino as Explanation of Gallium Anomaly

A **sterile neutrino** is a hypothetical particle that is postulated to interact only via gravity and not through any of the fundamental forces of the Standard Model of particle physics (like electromagnetism or the weak nuclear force)



Sterile Neutrino as Explanation For Gallium Anomaly

- The gallium anomaly could be explained if some of the electron neutrinos produced in the Sun or artificial sources are **oscillating into sterile neutrinos** before reaching the detectors. Since sterile neutrinos do not interact via the weak force, they would not trigger the reactions that gallium detectors are designed to capture.

- The **electron neutrino** would mix with sterile neutrinos through **neutrino oscillation**, described by quantum mechanical probabilities, meaning that only a fraction of the original electron neutrinos arrive at the detector as electron neutrinos, while some become sterile neutrinos that cannot be detected.

- The sterile neutrino explanation for the gallium anomaly is consistent with other neutrino oscillation anomalies, such as those observed in the **LSND** and **MiniBooNE** experiments, which also suggest oscillations into a fourth neutrino state with a mass-squared difference around **1 eV^2**.

Half-life of ^{71}Ge and the gallium anomaly

The half-life of 71Ge plays an important role in the detection of neutrinos in gallium-based experiments.

The half-life of 71Ge is crucial for timing the extraction and measurement of germanium isotopes in the detectors.

PHYSICAL REVIEW C **109**, 055501 (2024)

Editors' Suggestion

Half-life of ^{71}Ge and the gallium anomaly

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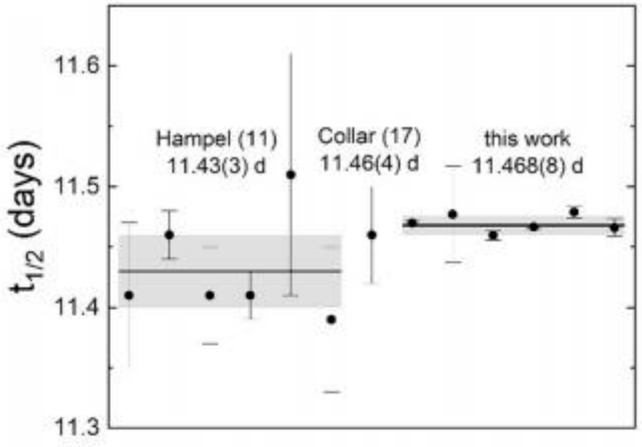

FIG. 4. Results from all reported measurements of the ^{71}Ge half-life since 1985.

Using a nuclear reactor at the McClellan Nuclear Research Center at the University of California, Davis, they irradiated "very pure germanium material," Norman said, producing germanium-71. They then analyzed the samples over 80 days to see how long it took the atoms to decay.

They arrived at a half-life of 11.468 days, extremely close to the 1985 measurement, ruling the half-life out as the explanation for the gallium anomaly

Summary

Gallium Anomaly Puzzled Scientists For Last Few Decades Where shortfall is observed in the number of neutrinos detected by gallium-based detectors (GALLEX, SAGE, and BEST) compared to theoretical predictions.

Various Possible Explanation of the Anomaly has been discussed in literature

We briefly discussed NME calculations with shell model and their role in cross section calculations and Gallium Anomaly … **Tensor part**

We mentioned how existence of sterile neutrinos can explain the Gallium Anomaly

Finally recently measured half-life of 71Ge confirm that half-life of 71Ge can't be the source of Gallium Anomaly

For now, the anomaly remains unsolved, with no sign of a resolution on the horizon. "It has us all puzzled," as Prof. Haxton said.

Useful References on Gallium Anomaly

- S.R. Elliott, V.N. Gavrin, W.C. Haxton, The gallium anomaly, Progress in Particle and Nuclear Physics Volume 134, January 2024, 104082

- S. R. Elliott, V. N. Gavrin, W. C. Haxton, T. V. Ibragimova, and E. J. Rule, Gallium neutrino absorption cross section and its uncertainty, PHYSICAL REVIEW C 108, 035502 (2023)

- E. B. Norman et al., Half-life of 71Ge and the gallium anomaly, Phys. Rev. C 109, 055501 (2024)

- J. Kostensalo, J. Suhonen, C. Giunti, P.C. Srivastava, The gallium anomaly revisited, Physics Letters B Volume 795, 10 August 2019, Pages 542-547

- W.C. Haxton, Cross section uncertainties in the gallium neutrino source experiments, Physics Letters B 431 1998 110–118

- https://www.quantamagazine.org/what-could-explain-the-gallium-anomaly-20240712/

- https://en.wikipedia.org/wiki/Soviet%E2%80%93American_Gallium_Experiment#The_gallium_anomaly

Thank you