Determination of the ^{37}Cl and ^{40}Ar neutrino capture cross sections

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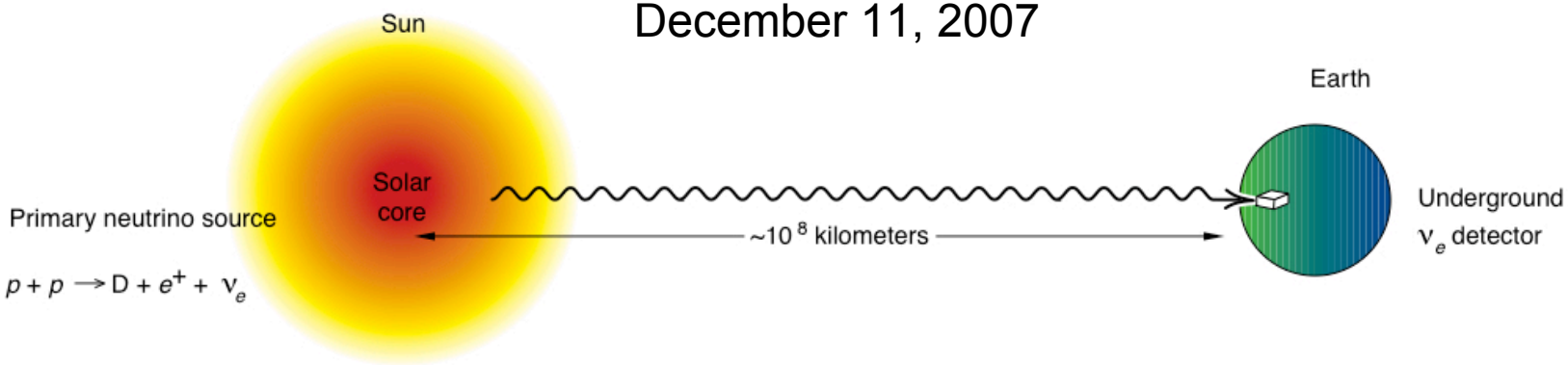


Figure from LANL Science: Celebrating the Neutrino

Solar neutrino work, 1964

- Sun thought to be powered by fusion of four protons into alpha particle
- Ray Davis, Jr. [2] reported counting rate from preliminary results of experiment to measure solar neutrinos
  - $^{37}Cl(\nu_e,e^-)^{37}Ar$
- Conversion from rate to neutrino flux depends on cross section for solar neutrinos to produce transitions from ^{37}Cl to ^{37}Ar
- Bahcall and Barnes [3] appealed to experimentalists to study the beta-decay of ^{37}Ca to ^{37}K
  - Isospin mirror reaction to neutrino capture on ^{37}C
  - Predict Gamow-Teller strengths, B(GT)
  - Convenient proton signature from decay of some ^{37}K states

^{37}Ca β-decay

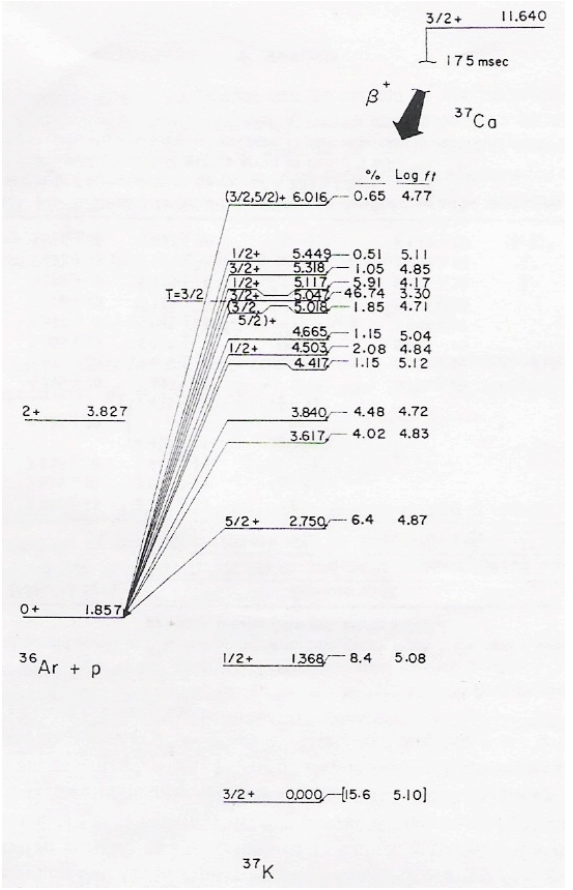
- Measured experimentally
  - Poskanzer et al., 1966 [4]
  - Sextro et al., 1974 [5]
- Governing equation [5]:

$$ft = \frac{6163.4s}{B(F) + \left(\frac{g_A}{g_V}\right)^2 B(GT)}$$

  - f: phase space factor
  - t: half life of decay
  - g_A/g_V: ratio of axial to vector coupling constants
  - B(x) is Fermi/GT strength
    - Relevant for ^{37}Cl neutrino capture cross section

^{37}Ca β-decay

- Sextro et al. [5] measured spectrum of delayed protons from decays of some excited states of ^{37}K
  - Assumed decays to ground state of ^{36}Ar
- ft value of ground state studied with mirror reaction
  - ^{37}Ar(EC)^{37}Cl
- ft value of first excited state determined from branching ratios and ^{37}Ca lifetime
- Bahcall used this data to calculate ^{8}B neutrino capture cross section
  - $(1.08 \pm 0.1) \times 10^{-42}$ cm^2



Decay scheme from Sextro et al. [5]

Charge Exchange

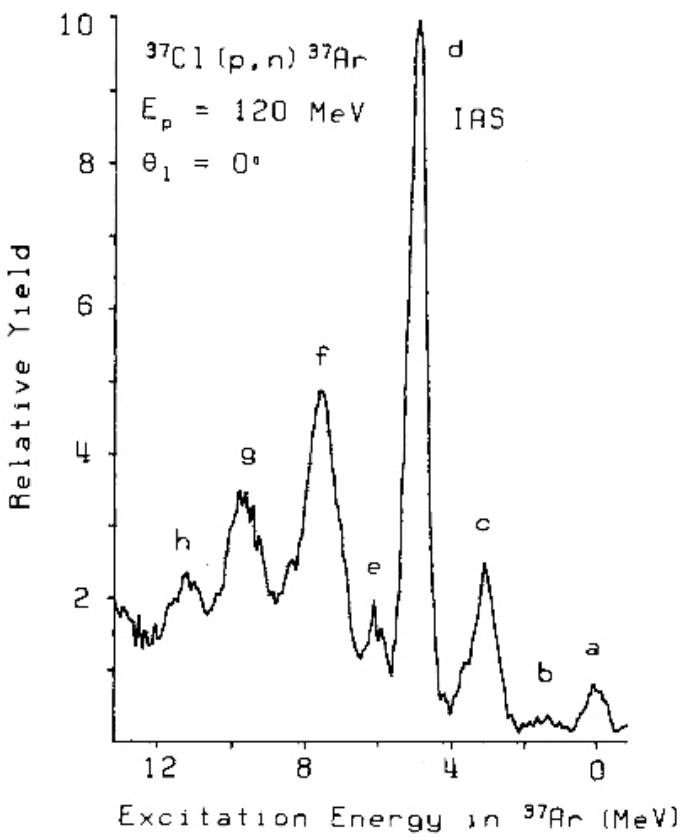
- Previous work showed that Fermi and GT strengths could be extracted from forward-angle cross section in Forward-angle cross section in (p,n) reaction [7]

$$\frac{d\sigma}{d\Omega}(\theta = 0^{\circ}) \approx \frac{\mu}{2\pi\hbar^2}\frac{k_f}{k_i}N_{\alpha}^{D}\left|J_{\alpha}\right|^2 B(\alpha)$$

  - k: wave number
  - α: Fermi/GT
  - N_{α}^{D}: calculable distortion factor
  - J_{α}: calculable factor
    - evaluated at q = 0
  - B(α): Fermi/GT strength
- Proportionality between cross section and GT strength
  - For transitions with negligible Fermi contributions

Charge Exchange

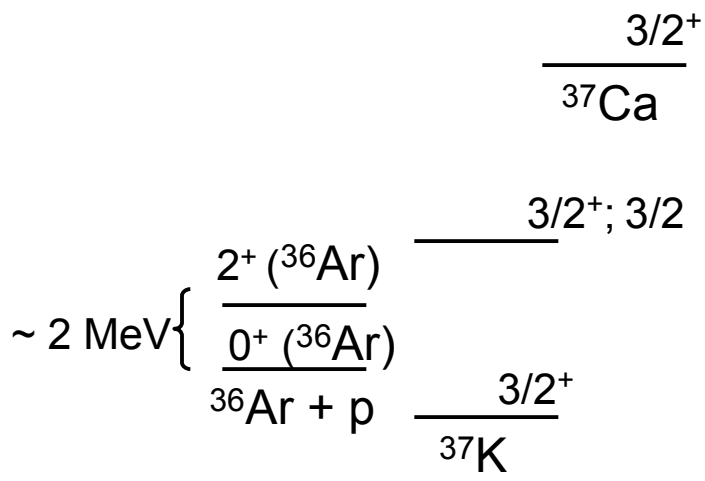
- In 1981, Rapaport et al. [7] measured cross section for the reaction $^{37}Cl(p, n)^{37}Ar$
  - bombarded ^{37}Cl targets with 120-MeV proton beam
  - measured neutron time-of-flight spectra
  - Calibrated to extract energies and absolute cross section magnitudes
  - Used ft value from Sextro to determine B(GT) for isobaric analog state
- Reported agreement with Sextro et al.
  - $(0.98 \pm 0.07) \times 10^{-42}$ cm^2



Neutron energy spectrum from Rapaport et al. [7]

Discrepancies in B(GT) distributions

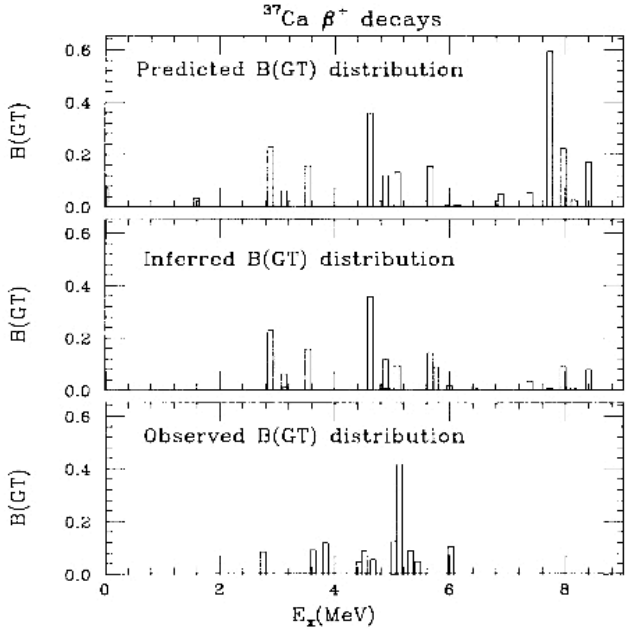
- In 1981, Adelberger and Haxton [8] noted discrepancies between the (p,n) and beta decay results
  - ^{8}B neutrino capture cross sections were in agreement
  - Distributions of B(GT) were not
- Rapaport et al. observed a peak in the B(GT) distribution at 7.65 MeV excitation energy in (p,n)
- Sextro et al. did not report peaks above 6.02 MeV
- Argued that the ^{37}Ca beta decay results were interpreted incorrectly
  - ^{37}K might decay to the 2^+ first excited state of ^{36}Ar, instead of the 0^+ ground state



Energy level spacing and values of J^{π} for relevant levels in the beta decay of ^{37}Ca

Discrepancies in B(GT) distributions

- If some levels in ^{37}K had been incorrectly assigned by Sextro et al.:
  - Energy level assignment shifted by 2 MeV
  - Phase space factors overestimated, B(GT) underestimated
- Adelberger and Haxton tested this idea with shell model
  - Good shell model agreement with (p,n) results
  - Shell model supported hypothesis that some levels in ^{37}K decay to the 2^+ first excited state of ^{36}Ar
- Resulting 4% increase in $^{37}Cl(\nu_e,e^-)^{37}Ar$ cross section
- Suggested that an experiment capable of distinguishing between decays to the ground and excited states of ^{36}Ar would be useful



Shell model and experimental distributions of B(GT) [7]

Further studies of ^{37}Ca β-decay

- Experiments detected 1.97-MeV γ from decay of ^{36}Ar first excited state
  - García, Adelberger, Swanson, Lang, Moltz - 1990 [9]
  - García et al.- 1991 [10]
- Confirmed that ^{37}K had some decays to the ^{36}Ar first excited state
  - Shell model underestimated this branching
- Large discrepancies between beta decay and (p,n) distributions of B(GT), especially between 1.4 and 3.2 MeV excitation energies in ^{37}K
- Neutrino capture cross section calculated from the Sextro et al. result should increase by 6%

Further investigation

- In 1991, Adelberger, García, Magnus, and Wells suggested sources of discrepancies in B(GT) [12]
  - (p,n) reaction might not accurately measure B(GT)
  - g_A might be renormalized in complex nuclei
- Prompted discussion
  - whether the (p,n) reaction was generally a good probe of GT strength
  - why experimental measurements gave systematically smaller B(GT) values than shell model predictions
- In 1992, Results of higher resolution $^{37}Cl(p, n)^{37}Ar$ experiment were reported by Wells et al. [18]
  - Consistent with earlier Rapaport et al. experiment

^{37}Cl cross section resolution

- In 1993, Iliadis et al. reported the discovery of a resonance in the ^{36}Ar(p,n)^{37}K reaction [18]
  - 3.24-MeV excited state of ^{37}K decays primarily by gamma emission
- Previous ^{37}Ca beta decay experiments had assumed the level decayed by proton channel
  - B(GT) assigned to this level had been underestimated
  - B(GT) for transition to first excited state of ^{37}K had been overestimated
- Reinterpreting the results of beta decay experiment with this information gave agreement with (p,n) results
- ^{8}B neutrino capture cross section (1.11 ± 0.08) x 10^{-42} cm^2
  - Results of the Davis experiment could be translated into neutrino flux

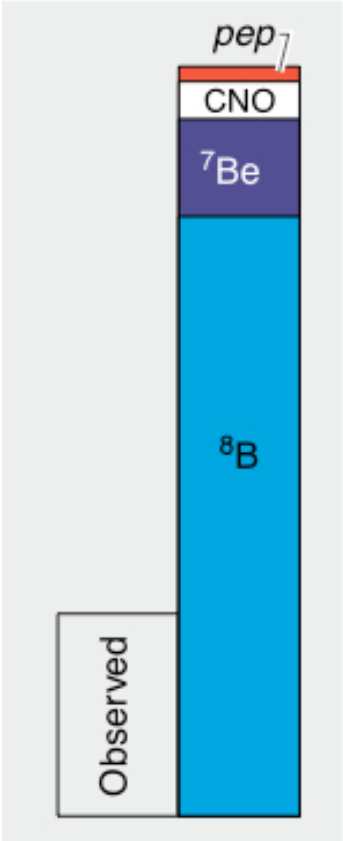


Figure from LANL Science: Celebrating the Neutrino

^{40}Ar cross section

- ICARUS collaboration [19] will study of neutrinos from various sources and search for proton decay
  - Liquid argon (LAr) time projection chamber
  - Require ^{40}Ar neutrino capture cross section
- Draft paper by Bhattacharya, Goodman, and García with results of (p,n) reaction [20]
  - Significant discrepancies with results of beta decay of ^{40}Ti, the isospin mirror
  - Distributions of B(GT) differ
  - Calculated cross sections for supernova neutrino capture differ significantly
- Further studies are needed

References

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- [20] preliminary results from private communication with A. Garcia

(Reference numbering scheme taken from summary.)