Low lying states in ^{127}Xe: Implications for the efficiency of an ^{127}I solar ν detector

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Spectroscopic information about ^{127}Xe is obtained by studying γ rays following the β decay of ^{127}Cs. The results are of interest for determining the efficiency of a proposed ^{127}I-based ν detector.

Haxton[1] has recently pointed out that the $^{127}\mathrm{I}(\nu,e)^{127}$Xe reaction could be used as an efficient detector of solar neutrinos, with an estimated ν-capture rate per unit detector volume roughly an order of magnitude higher than the $^{37}\mathrm{Cl}(\nu,e)^{37}$Ar detector at Homestake. Such a detector could also provide new information, since it would have different sensitivities to ^{8}B and ^{7}Be neutrinos than the ^{37}Cl detector. The cross section for capturing ^{7}Be neutrinos (E_ν =862 keV) depends only on the strength of the lowest lying Gamow-Teller (GT) transition, i.e., ^{127}I g.s. $(\frac{5}{2}^+) \rightarrow$ 125 keV $(\frac{3}{2}^+)$. This strength could be estimated by an $^{127}\mathrm{I}(p,n)$ measurement if sufficient energy resolution can be achieved. Two neighboring states with $J^\pi = (\frac{1}{2},\frac{3}{2})^+$ were known to lie at 321 and 412 keV. If these levels had $J^\pi = \frac{3}{2}^+$ then they could be excited with enough strength in the 0° (p,n) reaction that they would need to be clearly resolved from the 125 keV level. Thus, the required resolution depends on which of the two possible assignments is correct. Alternatively, the efficiency of an ^{127}I detector could be determined using a ^{65}Zn source[3] (E_ν = 1343 keV) of known strength. Since this source could excite Gamow-Teller transitions to states up to 680 keV in ^{127}Xe, spectroscopic information about these levels is needed in order to extract the detector efficiency for ^{7}Be neutrinos. We have performed an experiment to determine the spin of ^{127}Xe low lying states, that could affect the interpretation of a 0° (p,n) measurement. We also determined spectroscopic properties of all levels below 680 keV that could affect the ^{65}Zn source calibration of the ν detector.

We performed a γ-γ angular correlation experiment in ^{127}Xe, by preparing a ^{127}Cs source which β^+ decays ($t_{1/2}$ = 6.25 h) to ^{127}Xe. Samples of CaI were irradiated in air for a few hours with a 30 particle nA 60 MeV α beam from the University of Washington tandem/superconducting linear accelerator. The Cs was chemically separated and concentrated using the procedure described in Ref. 2. Gamma rays were registered by three GeLi detectors positioned at 7.5 cm from the source. One of the detectors was held fixed with respect to the source while the other two were mounted on movable arms, allowing us to vary the angles between the three pairs of detectors in steps of about 30°. Coincidence and singles spectra were recorded simultaneously in order to properly normalize our data. A typical coincident γ-ray spectrum is shown in Fig. 1. Many corrections, such as for dead time and pulse pileup, that are often insignificant, turn out to be essential when dealing with a source with a rather short lifetime as ^{127}Cs. We determine dead time and pileup corrections using a pulser triggered by a fixed NaI detector that also viewed the ^{127}Cs source. Corrections varied from about 1% to 20% according to the counting rate. We were able to check our dead-time correction procedure by reproducing the known lifetime of ^{127}Cs using our singles spectra.

We extracted γ-decay branching ratios for low lying levels in ^{127}Xe from the singles data. Our results are shown in Fig. 2 and Table I. We observed some previously unreported branches and found significant disagreement with existing data[4] for other transitions.

We extracted a_2 coefficients for several γ-γ cascades

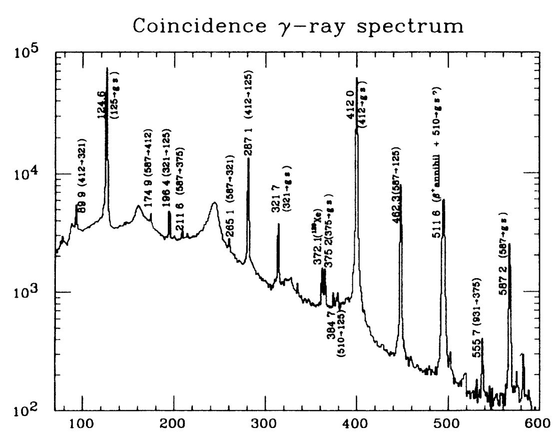

FIG. 1. Energy spectrum of one of our GeLi detectors in coincidence with an event (including annihilation radiation) in any of the two other detectors.

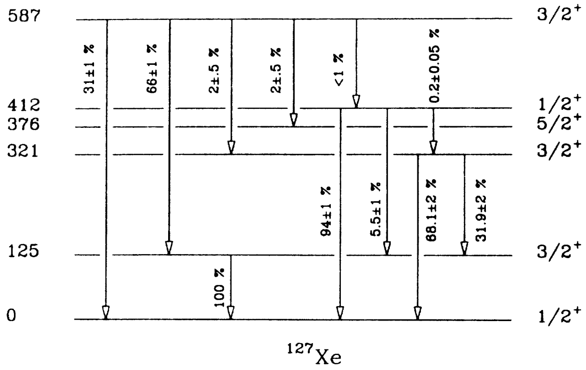

FIG. 2. Decay scheme of low lying ^{127}Xe levels. Gamma-ray branching ratios are from this work.

in ^{127}Xe. These coefficients were obtained using angular correlation attenuation coefficients (Q factors) measured with a ^{22}Na source (taking advantage of the fact that the two 511 keV γ rays are emitted in opposite directions). The resulting mixing ratios and level spins are shown in Table II.

The 321 keV level. We measured a branching ratio of 0.21 ± 0.05 % for the previously unreported 412 keV $\rightarrow$ 321 keV transition . Our a_2 coefficient for the 412 keV $\rightarrow$ 321 keV $\rightarrow$ 0 cascade differs from zero by more than 7σ. This excludes the $J = \frac{1}{2}$ possibility for this level and confirms the $J^\pi = \frac{3}{2}^+$ assignment of Ref. 4.

The 412 keV level. Since the 125 keV level is known to be $J^\pi = \frac{3}{2}^+$, any correlation with the 125 keV$\rightarrow$g.s. transition can contain terms involving only Legendre polynomials of order 0 and 2. Our a_2 coefficient for the 412 keV$\rightarrow$ 125 keV$\rightarrow$ 0 (see Fig. 3) excludes by more than 4σ the $J = \frac{3}{2}$ possibility for the 412 keV level. Our results for these and other transitions are summarized in Table II. In Fig. 4 we present a level scheme of ^{127}Xe

TABLE I. γ decay branching ratios in ^{127}Xe.

$E_x^i \rightarrow E_x^f$	$I_i^\pi \rightarrow I_f^\pi$	Branching ratio (this work)	Branching ratio (Ref. 4)
587 → g.s.	$\frac{3}{2}^+ \rightarrow \frac{1}{2}^+$	$31 \pm 1\%$	46%
587 → 125	$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	$66 \pm 1\%$	52%
587 → 321	$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	$2 \pm 0.5\%$	
587 → 376	$\frac{3}{2}^+ \rightarrow \frac{5}{2}^+$	$2 \pm 0.5\%$	
587 → 412	$\frac{3}{2}^+ \rightarrow \frac{1}{2}^+$	$< 1\%$	$< 2\%$
412 → g.s.	$\frac{1}{2}^+ \rightarrow \frac{1}{2}^+$	$94.3 \pm 1\%$	94%
412 → 125	$\frac{1}{2}^+ \rightarrow \frac{3}{2}^+$	$5.5 \pm 0.5\%$	6%
412 → 321	$\frac{1}{2}^+ \rightarrow \frac{3}{2}^+$	$0.2 \pm 0.5\%$	
321 → g.s.	$\frac{3}{2}^+ \rightarrow \frac{1}{2}^+$	$68.1 \pm 2\%$	70%
321 → 125	$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	$31.9 \pm 2\%$	30%

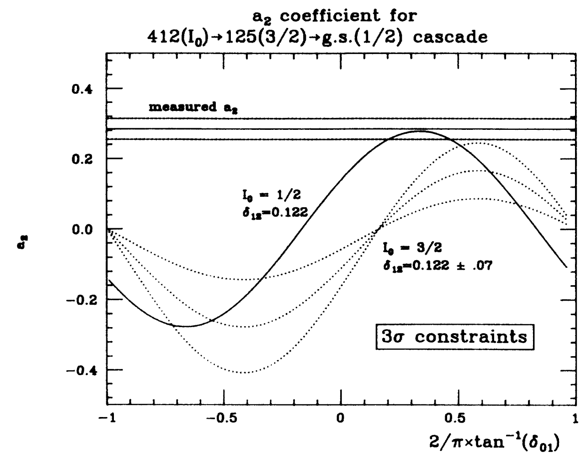

FIG. 3. a_2 coefficient for the $412(I_0^+) \rightarrow 125(\frac{3}{2}^+) \rightarrow$ g.s. $(\frac{1}{2}^+)$ cascade as a function of the mixing ratio for the first transition. Continuous line: $I_0 = \frac{1}{2}$. Dotted line: $I_0 = \frac{3}{2}$. The mixing ratio for the second transition was determined by reanalyzing Geiger's (Ref. 7) results using currently accepted values for the spins of the states. The normally quoted (Refs. 8 and 9) value of 0.09 ± 0.02, was obtained under the [now known to be incorrect (Ref. 6)] assumption of $J = \frac{5}{2}$ for the 125 keV level and $J = \frac{3}{2}$ for the g.s.

showing only those states relevant to determining the efficiency of an ^{127}I neutrino detector. Our results suggest that an unambiguous determination of the GT strength for ^{7}Be neutrinos (i.e., to the 125 keV state in ^{127}Xe) would require an ^{127}I(p,n) measurement with an energy

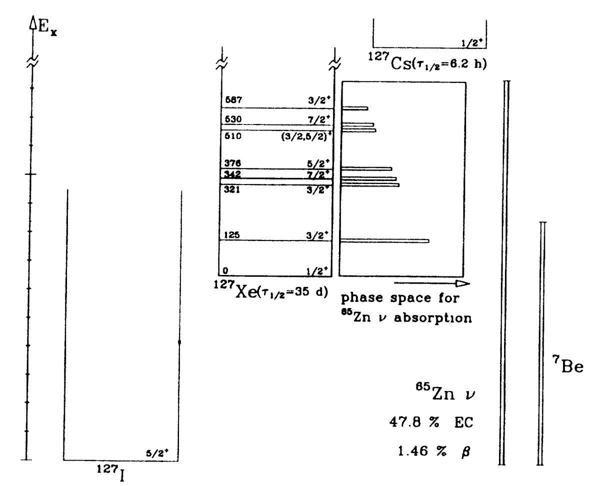

FIG. 4. Energy level diagram of ^{127}Xe including only levels of interest (i.e., energies below 680 keV and $J^\pi = \frac{3}{2}^+, \frac{5}{2}^+$, or $\frac{7}{2}^+$) for calibrating the efficiency of an ^{127}I ν-detector using either the ^{127}I(p,n) reaction or a ^{65}Zn ν source. The inset shows the expected feeding of ^{127}Xe levels by monoenergetic ^{65}Zn ν's under the assumption that all transitions have the same B(GT).

TABLE II. Mixing ratios and spins of levels in ^{127}Xe from $I_0 \rightarrow I_1 \rightarrow I_2$ γ-γ cascades fed in the β-decay of ^{127}Cs. δ_{01} and δ_{12} are the $E2/M1$ mixing ratios for the first and second γ-ray transition, respectively. Question marks are used for unknown mixing ratios.

$E_x^0 \rightarrow E_x^1 \rightarrow E_x^2$	a_2	I_0^π	$\rightarrow$	I_1^π	$\rightarrow$	I_2^π	δ_{01}	δ_{12}
321 → 125 → g.s.	-0.11 ± 0.05[a]	$\frac{3}{2}^+$ [a,b]	→	$\frac{3}{2}^+$	→	$\frac{1}{2}^+$	−0.02 to +0.01[a]	+0.10 to +0.14[c]
411 → 125 → g.s.	$+0.28 \pm 0.01$[a]	$\frac{1}{2}^+$ [a]	→	$\frac{3}{2}^+$	→	$\frac{1}{2}^+$	+0.24 to +0.85[a]	+0.10 to +0.14[c]
411 → 321 → g.s.	$+0.35 \pm 0.05$[a]	$\frac{1}{2}^+$ [a]	→	$\frac{3}{2}^+$ [a,b]	→	$\frac{1}{2}^+$	−0.02 to +0.02[a]	+0.86 to +0.93[b]
587 → 125 → g.s.	$+0.12 \pm 0.02$[a]	$\frac{3}{2}^+$ [b]	→	$\frac{3}{2}^+$	→	$\frac{1}{2}^+$	+0.21 to +1.01[a]	+0.10 to +0.14[c]
587 → 321 → g.s.	-0.62 ± 0.10[a]	$\frac{3}{2}^+$ [b]	→	$\frac{3}{2}^+$	→	$\frac{1}{2}^+$	+0.80 to +1.40[a]	+0.86 to +0.93[b]
931 → 125 → g.s.	-0.05 ± 0.01[a]	?	→	$\frac{3}{2}^+$	→	$\frac{1}{2}^+$	?	+0.10 to + 0.14[c]

[a] This work.
[b] Reference 5.
[c] Our reanalysis of Geiger's result (Ref. 7).

resolution better than 200 keV.

We also show the phase space factor for the ^{127}I(ν, e) transition to various levels in ^{127}Xe excited by monoenergetic ^{65}Zn neutrinos (E_ν =1.343 MeV). These would be proportional to the ν absorption cross section if all the unknown Gamow-Teller matrix elements had the same value. If that were the case, only 26% of the ν absorption cross-section would be due to the transition to the 125 keV level in ^{127}Xe. Finally, our spectroscopic data provides a test of any nuclear model used in predicting the ν cross section.

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