Communications

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Feasibility of ^{81}Br as a solar neutrino detector

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The ^{81}Kr^m to ^{81}Br electron capture rate has been measured and found to have a logft value of 4.58±0.11. This result implies ^{81}Br is a feasible target for solar neutrino capture.

[RADIOACTIVITY Measured branching ratio ^{81}Kr^m electron capture, deduced logft for solar neutrino capture.]

One of the enigmas of modern physics is the discrepancy between the theoretical expectations and experimental observations of the solar neutrino ($\nu_\odot$) flux.[1,2] In order to resolve this problem, a number of experiments have been proposed which would be sensitive to lower energy neutrinos than those seen in the Davis ^{37}Cl experiment. A recent review by Bahcall[3] discussed the advantages and disadvantages of a number of these experiments. One particular experiment, originally proposed by Scott,[4] involves the detection of ^{81}Kr in Br salts produced by the reaction ^{81}Br$(\nu, e^-)^{81}$Kr^m (13 s) leading to the formation of the 2.1×10^5 yr ground state. This reaction has a threshold energy of 512 keV as compared to the threshold of 814 keV for the ^{37}Cl$(\nu, e)^{37}$Ar reaction investigated by Davis. It is most sensitive to the ^{7}Be solar neutrinos, which are thought to be second only to the pp neutrinos in flux. Furthermore, with such a long half-life, the neutrino produced ^{81}Kr concentration represents the average integrated flux over the past 0.3 Myr. Thus its measurement in bromine containing minerals would serve to rule out the possibility that the solar neutrino problem results from a temporary fluctuation. Alternatively, a live experiment, very similar to the original Cl based experiment, could be done with Br compounds, a possibility of current interest.[5]

The most serious objection to the use of ^{81}Br as a solar neutrino detector has been that the cross section for neutrino capture was unknown. We have attempted to determine the $\nu_\odot$ capture cross section by measuring the logft value for the inverse process, the electron capture decay of the 190 keV 13 s isomeric $\frac{1}{2}^-$ state in ^{81}Kr.

The experimental arrangement we employed is shown in Fig. 1. A target consisting of a mixture of graphite powder with KBr was bombarded by 22 MeV protons from the Princeton AVF cyclotron. The beam current was limited to 1.5 μA as higher currents caused the KBr to evaporate from the target. The isotopes of Kr produced by the (p, n) reaction diffused out of the target into the ion source where they were ionized. After

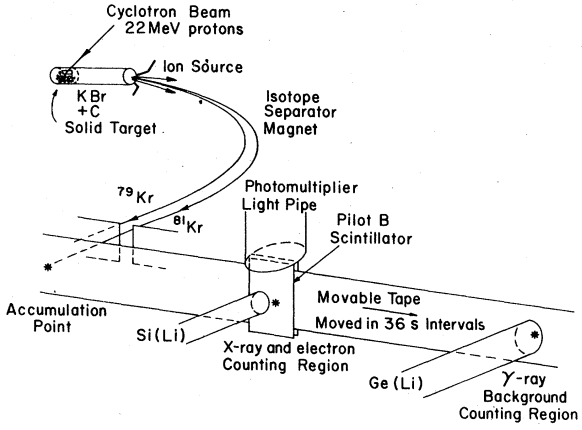

FIG. 1. Schematic of the experimental setup showing mechanism of source preparation and geometry of x ray, electron, and γ ray detectors.

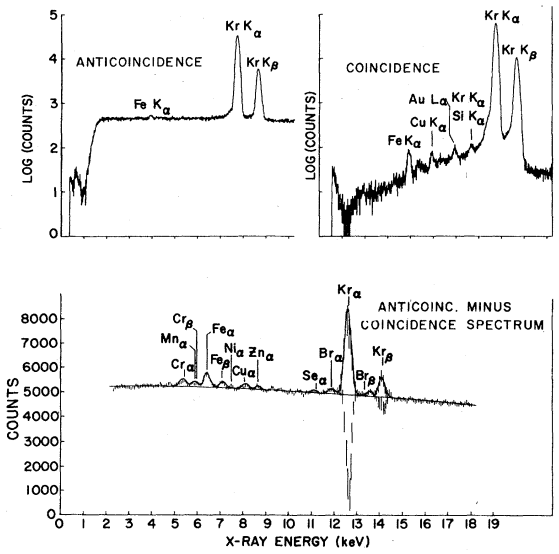

FIG. 2. Si(Li) x-ray spectra observed from decay of $^{81}Kr^{m}$. Clockwise from upper left (i) the spectrum in anticoincidence with electron detector events, (ii) spectrum in coincidence with electron events, and (iii) two superimposed spectra resulting from subtraction of a scaled coincidence spectrum from the anticoincidence spectrum. Slight over and under subtraction illustrate the insensitivity of the region near the Br x rays to the tail of the Kr x-ray peak. Feβ, etc. stand for Fe $K\beta$. Expected positions for selected x-ray peaks are indicated by vertical lines.

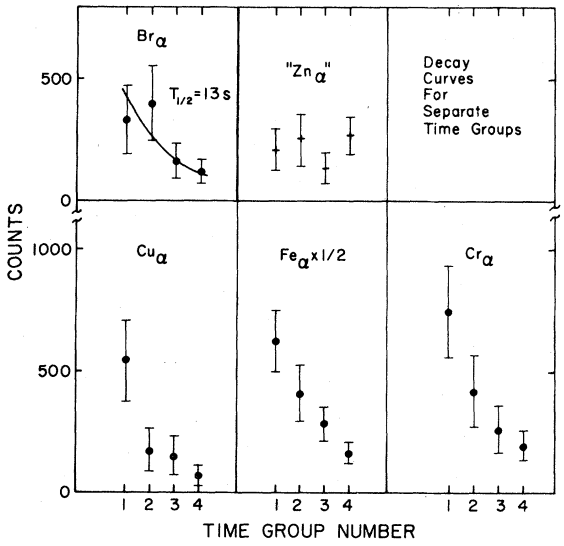

FIG. 3. Decay curves for peaks in the subtracted x-ray spectrum. The Br $K\alpha$ data are fitted with a 13 s half-life decay curve.

acceleration to 60 keV, these ions were mass analyzed by the Princeton on-line isotope separator. The mass 81 ions were implanted in a moveable aluminized Mylar tape used in a single pass mode. After accumulating for 36 s, the $^{81}Kr^{m}$ sources were automatically moved into a counting region where they were viewed by a Si(Li) detector and a scintillator/photomultiplier as diagrammed in Fig. 1. The energy resolution of the Si(Li) counter was about 250 eV at the 12.65 keV krypton $K\alpha$ x ray. Two thin plates (20 mil) of Pilot B scintillator surrounded the tape. The photomultiplier/scintillator had an overall efficiency of 79% for detection of the 190 keV $^{81}Kr^{m}$ conversion electrons. During the 36 s counting period, the data were multiscaled to form four sequential spectra of 9 s each. For the one second interval during which the tape was moved, the electronics were gated off. After 36 s, each source then moved in front of the Ge(Li) counter shown in the diagram where the gamma spectrum was recorded to search for possible contamination.

Pulses from the Si(Li) detector were used to start a time-to-amplitude converter which was stopped by either the photomultiplier signal (when present) or a 120 ns delayed repeat of the start signal. In Fig. 2, the spectrum labeled anticoincidence consists of x rays observed in the Si(Li) detector unaccompanied by a signal in the photomultiplier. Since each Kr x ray originating from the internal conversion decay of $^{81}Kr^{m}$ is always associated with a conversion electron, the Kr $K\alpha$ and $K\beta$ peaks seen in the anticoincidence spectrum result from inefficiency of the anticoincidence counter. The coincidence spectrum has exactly the same instrumental line shape and gain as the anticoincidence spectrum; backscattering, escape peaks, and pileup all affect both line shapes the same way. Since the coincidence spectrum does not have the large Compton background evident in the anticoincidence spectrum, it provides an accurate line shape for subtraction from the anticoincidence spectrum. The resulting spectrum is shown in the bottom of Fig. 2. The peaks in the subtracted spectrum are mainly due to the x-ray fluorescence of elements in the Si(Li) detector itself. The Cr, Mn, Fe, and Ni peaks result from the stainless steel casing of the detector. The Au $L\alpha$ x-ray peak, prominent in the coincidence spectrum, is from fluorescence of a 200 Å layer of gold on the front contact of the Si(Li) crystal; the Cu lines come from other components of the detector. Although Au $L\beta$ lines lie near the energy region of interest, a spectrum taken with a 20 mg/cm^2 Au foil placed in front of the Si(Li) detector indicated that the intensity of the Au $L\beta$ lines was completely negligible at the Br $K\alpha$ energy. The origin of the peak on the low energy side of the Kr $K\beta$ peak is not understood.

The data were accumulated in 1024 channel buffers using the program ACQUIRE.[6] For the analysis the data were first smoothed over 8 channels, then summed over 4 channels. To produce the spectra of Fig. 2, all four time groups were added. All peaks were fitted with curves having the same shape as the Kr $K\alpha$ line in the coincidence spectrum. The Compton background in the subtracted spectrum was fitted with a quadratic curve. In the subtracted spectrum the statistical error is indicated by the length of the bars.

After a six day run with 24 net hours of accumulation, the number of Kr $K\alpha$ x-ray events observed was 4.7×10^6. The corresponding number of Br $K\alpha$ x-ray events observed was 890 ± 210. The error quoted is the standard error determined by the least squares fit. As a check on the lifetime of the decays producing this peak, we have analyzed the data in each of the four nine-second groups, and plotted the number of counts found for various peaks in Fig. 3. The decay curves for most of the peaks in the spectrum follow the 13 s half-life decay of the ^{81}Kr^m isomer with the exception of the peak in the neighborhood of "Zn" $K\alpha$ x rays. The least squares fit to the Br $K\alpha$ decay rate for a 13 s half-life is shown in Fig. 3. However, because of the poor statistics, attribution of the bromine x rays to a possible long lived parent cannot be excluded by the decay rate alone. The three possible Br x-ray generating isotopes conceivably produced are ^{79}Kr (35 h), ^{80}Br^m (4.42 h), and ^{79}Br^m (4.9 s). Contributions from ^{79}Kr and ^{80}Br^m may be excluded on the basis of the short dwell time, relative to their lifetime, in front of the detector. Based on an upper limit for the number of 207 keV γ rays observed in the Ge(Li) associated with the ^{79}Br^m decay, the number of ^{79}Br^m x rays is less than 5% of the total Br x rays observed.

Conceivably Br $K\alpha$ x rays in the subtracted spectrum could arise from fluorescence of Br atoms by 190 keV gamma rays (fluorescence by Kr $K\beta$ x rays or internal conversion electrons is removed by the coincidence subtraction). However, because of the much greater cross section for fluorescence of Br atoms by Kr $K\beta$ x rays, the attribution of any significant fraction of the Br $K\alpha$ events in the subtracted spectrum to this mechanism would require a prominent Br $K\alpha$ peak in the coincidence spectrum, contrary to observation.

With the conversion coefficient $e/\gamma = 0.49\pm0.01$ from Ref. 7, and fluorescence yields $\omega_K = 65\pm3\%$ for Kr and $62\pm3\%$ for Br, we find the branching ratio

$$\frac{K\text{ capture}}{\text{All }^{81}\text{Kr}^m\text{ decays}} = 0.297\,\frac{\text{Br }K\text{ x rays}}{\text{Kr }K\text{ x rays}}$$

$$= (5.64\pm1.38)\times10^{-5}.$$

Using the log$f$ factors of Gove and Martin[8] and interpreting the events in this peak as Br $K\alpha$ x rays following the electron capture decay of ^{81}Kr^m leads to a logft value of 4.58 ± 0.11 for this decay. For the solar neutrino capture from the $\frac{3}{2}^-$ ^{81}Br ground state to the $\frac{1}{2}^-$ ^{81}Kr isomer the corresponding log$ft = 4.88\pm0.11$. This logft value for solar neutrino capture implies that, so far as production rate is concerned, the use of ^{81}Br as a solar neutrino detector is feasible.

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