β decay of ^{49}Cr†

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The spectrum of γ rays following the β decay of ^{49}Cr has been measured with a 65 cm^3 Ge(Li) detector. β-decay branches to the following states in ^{49}V were observed (logft values in parentheses): ground state (5.6), 91 keV (4.9), 153 keV (4.7), 1514 keV (5.7), 1661 keV (6.0), 2182 keV (6.9), 2235 keV (6.6), and 2309 keV (7.1). β-decay branches to the last three states have not been previously reported. In contrast to an earlier β-decay experiment, β branches to the 748 ($3/2^+$), 1021 ($11/2^-$), and 1140 ($5/2^+$) keV states were not observed.

[RADIOACTIVITY ^{49}Cr [from $^{46}Ti(\alpha,n)$]; measured E_γ, I_γ; deduced logft. ^{49}V deduced levels, J, π. Enriched targets, Ge(Li) detector.]

I. INTRODUCTION

The present investigation of the ^{49}Cr β decay was prompted by inconsistencies between the results of a recent study[1] of the $^{46}Ti(\alpha, p\gamma)^{49}V$ reaction and an earlier measurement[2] of the spectrum of γ rays following the β decay of ^{49}Cr.

Okon *et al.*[2] report that levels at 0, 90.7, 152.9, 754.0, 1021.3, 1141.9, 1514.2, and 1661.6 keV are populated by the β decay, but they list logft values only for the lowest three states. Of particular concern are the levels at 754.0, 1021.3, and 1141.9 keV which have been assigned spin-parity values of $\frac{3}{2}^+$, $\frac{11}{2}^-$, and $\frac{5}{2}^+$, respectively, in a number of investigations,[1,3-6] and hence cannot be populated by allowed β decay from the $\frac{5}{2}^-$ ground state of ^{49}Cr. Okon *et al.*[2] mention the spin assignment of $\frac{3}{2}^+$ to the 748 keV state but do not comment on the significance of their observation of a β-decay branch to it. In addition, the excitation energies of 754.0 and 1141.9 keV reported in Ref. 2 differ by considerably more than the quoted uncertainty of 0.3 keV from the adopted values of 748.1 and 1140.6 keV.[7] The 1021.3 keV line in the γ spectrum of Ref. 2 appears broader than other lines in that spectrum.

Our results are in strong disagreement with those of Okon *et al.*[2] With considerably greater statistics we find no evidence for ^{49}Cr β-decay branches to the 748, 1021, or 1140 keV states. We conclude that the spectrum peaks identified in Ref. 2 as γ rays from the 748 and 1021 keV states result from pulse pileup. In addition, the relative intensities we have measured for the γ rays from the 1514 and 1661 keV levels are about an order of magnitude lower than those quoted in Ref. 2.

II. EXPERIMENTAL PROCEDURE

Sources of ^{49}Cr were produced with the $^{46}Ti(\alpha, n)^{49}Cr$ reaction using a 15 MeV α beam from the University of Pennsylvania tandem accelerator. The targets consisted of approximately 5 mg of TiO_2 powder enriched to 81% in ^{46}Ti and were encapsulated between a 250 μm Ta backing and a 6.3 μm Ta window. The targets were irradiated for about one hour and γ spectra were accumulated following the irradiation for approximately the same period of time. Two targets were used and the process was repeated a number of times.

A 65 cm^3 Ge(Li) detector was used to detect γ rays. Several precautions were taken to observe the weaker γ rays above 511 keV. A lead shield around the detector considerably reduced room background. The ^{49}Cr sources were placed in an antiannihilation arrangement similar to that described by van Lieshout *et al.*[8] in order to reduce the counting rate and pulse pileup due to the intense annihilation radiation. In addition, a 1 mm thick Ta sheet was used to selectively absorb the strong low energy lines. Electronic pileup rejection circuitry was employed to further reduce the effect of low energy γ rays on the higher energy portion of the spectrum.

The γ spectrum from the ^{49}Cr source was accumulated in a 4096 channel analyzer. Spectra were accumulated during 10 min intervals and then recorded on magnetic tape under computer control. This procedure permitted the measurement of the lifetimes of individual lines to assist in their identification. A periodic energy calibration was provided by measuring the ^{88}Y γ spectrum between irradiations.

To measure the relative intensity of annihilation radiation, a γ spectrum was accumulated with the ^{49}Cr source placed between 6.4 mm thick Plexiglas blocks which served to stop positrons near the source. A spectrum was also accumulated in the antiannihilation geometry without the Ta absorber to measure the relative intensities of the 62, 91, 153, and 1361 keV lines. To identify lines from long-

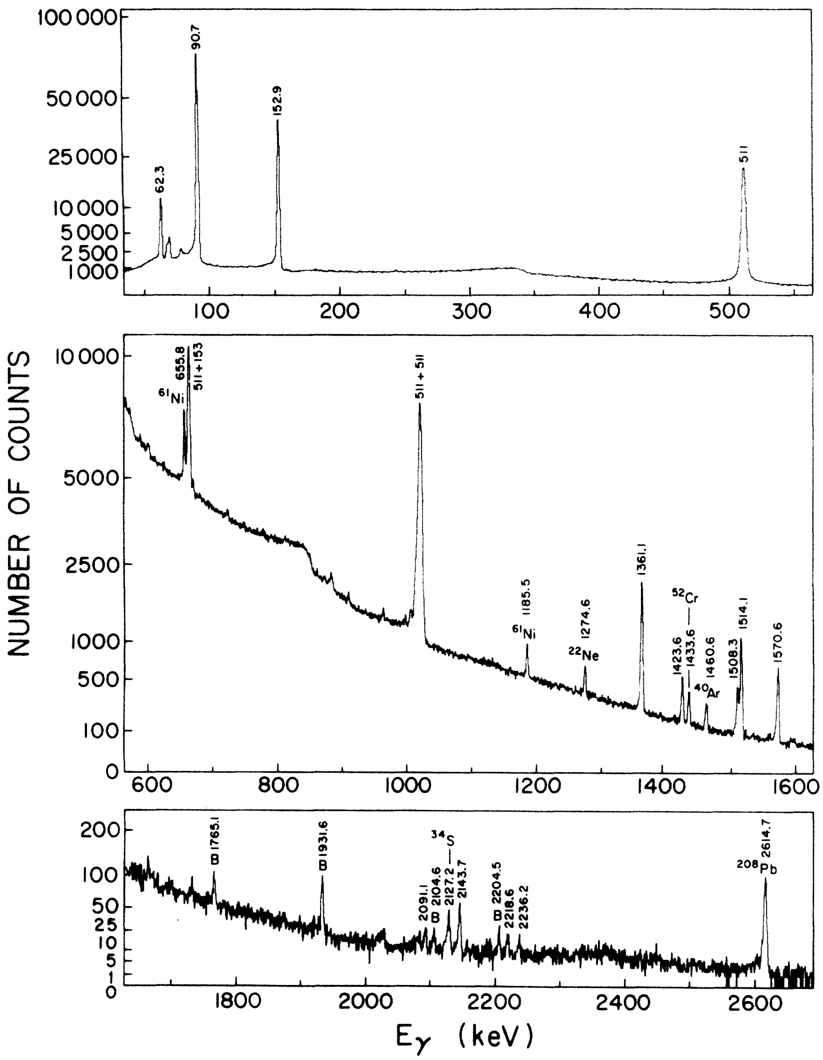

FIG. 1. The spectrum of γ rays emitted following the β decay of ^{49}Cr. The square root of the number of counts is graphed along the y axis and the labeling of the peaks is discussed in the text. The three segments of this spectrum represent different accumulation times.

lived activities in the source and from the room background, one γ spectrum was accumulated during the interval from 4 to 12 h after irradiation and another was accumulated without the source.

The relative efficiency of the Ge(Li) detector as a function of γ energy was determined using ^{56}Co, ^{154}Eu, and ^{133}Ba sources whose relative γ-ray intensities are accurately known.[9-11] This efficiency calibration was made for each of the geometries in which the ^{49}Cr spectrum was measured.

III. RESULTS

The spectrum of γ rays from the β decay of ^{49}Cr is shown in Fig. 1. The γ rays from ^{49}V which have been identified by their lifetime and energy are labeled in the figure with their energies (keV). Lines with a lifetime significantly different from that of ^{49}Cr and those from the room background are labeled with their energy and with either the letter "B" or the nucleus in which the observed γ transition takes place. The two lines between 62 and 91 keV are x rays.

Table I presents a summary of the intensities of the ^{49}V γ rays observed in this experiment. These intensities have been corrected for detector efficiency and are normalized to that of the 91 keV line. It should be noted that the intensities of the γ rays between 1361 and 1571 keV differ by about an order of magnitude from those of Ref. 2 and the lines above 1571 keV have not been previously reported.

TABLE I. Relative intensities of γ rays from the β decay of ^{49}Cr.

E_γ (keV)	Relative intensity	Identification
62.3 ± 0.1	31.5 ± 3.8	152.9 → 90.7
90.7 ± 0.1	100	90.7 → g.s.
152.9 ± 0.1	52.0 ± 2.4	152.9 → g.s.
511	327 ± 16	$\gamma^{\pm}$
1361.1 ± 0.2	$(1.02 \pm 0.12) \times 10^{-1}$	1514.1 → 152.9
1423.6 ± 0.2	$(2.42 \pm 0.29) \times 10^{-2}$	1514.1 → 90.7
1508.3 ± 0.2	$(2.31 \pm 0.28) \times 10^{-2}$	1661.2 → 152.9
1514.1 ± 0.2	$(5.59 \pm 0.66) \times 10^{-2}$	1514.1 → g.s.
1570.6 ± 0.2	$(3.52 \pm 0.42) \times 10^{-2}$	1661.2 → 90.7
2091.1 ± 0.7	$(7.48 \pm 1.56) \times 10^{-4}$	2181.7 → 90.7
2143.7 ± 0.6	$(1.73 \pm 0.26) \times 10^{-3}$	2235 → 90.7
2218.6 ± 1.0	$(3.56 \pm 1.07) \times 10^{-4}$	2309 → 90.7
2236.2 ± 1.0	$(4.23 \pm 1.19) \times 10^{-4}$	2235 → g.s.

A diagram of the levels populated by the β decay is shown in Fig. 2. The 1155 keV level is included in the diagram only to complete the γ-decay scheme. There is no evidence that the 1155 keV level is directly populated by the β decay. The transitions between levels in ^{49}V are labeled by their observed γ-ray energies and by the number of transitions (electromagnetic plus internal conversion) per 100 decays of ^{49}Cr.

The β-decay and electron-capture branching ratios and the $\log ft$ values are listed in Fig. 2. The calculation of $\log ft$ values follows that of Gove and Martin.[12] The measured internal conversion coefficients of 0.14,[13] 0.035,[14] and 0.078[14] were used for the 62, 91, and 153 keV transitions, respectively. The adopted value[7] of 42 min was used for the ^{49}Cr half-life.

IV. DISCUSSION

Ground, 91, and 153 keV states. The $\log ft$ values measured for the allowed β-decay branches to these three states are in good agreement with those reported by Cheung and Mark[15] and by Okon *et al.*[2] Excellent statistical accuracy is easily obtained for these γ rays. The principal uncertainty in determination of the branching ratios lies in the calibration of the relative efficiency of the Ge(Li) detector.

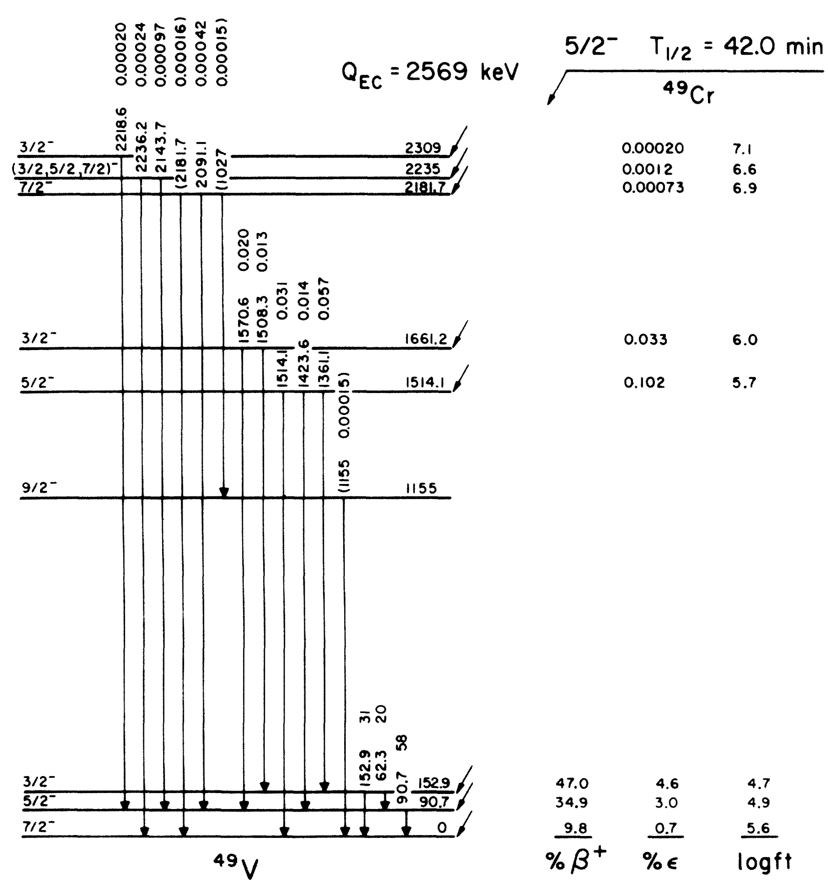

FIG. 2. β-decay scheme of ^{49}Cr. Only levels populated in the β decay are shown except for the 1155 keV level.

748 keV state. We see no evidence of the β-decay branch reported by Okon *et al.*[2] to this $\frac{3}{2}^+$ state and have obtained an upper limit of 0.0037% ($\log ft \geq 8.0$). When the 1 mm Ta absorber was removed, lines at 601 and 663 keV appeared strongly in the spectrum. Only the 663 keV line is still visible in the spectrum in Fig. 1, but it is strongly attenuated by the Ta absorber. The selective absorption of these lines by 1 mm of Ta (whose γ transmission increases rapidly above 100 keV) and the energies of these lines indicate that they result from the pileup of pulses from the 511 keV γ rays with those from the 91 and 153 keV γ rays. These pileup peaks were misinterpreted as γ rays from a state at 754 keV in Ref. 2.

1021 keV state. A β-decay branch to this $\frac{11}{2}^-$ level was reported in Ref. 2. A broad peak at 1020 keV can be seen in Fig. 1. This peak is formed principally by the pileup of two pulses from 511 keV γ rays. Although it appears strong in Fig. 1, the 511 keV pileup peak is only 5×10^{-4} as strong as the 511 keV line. There is no evidence that the 1021 keV level is populated in the β decay, although a weak 1021 → 0 keV γ ray (the only decay mode) would be masked by the pileup peak.

1140 keV state. A β branch to this $\frac{5}{2}^+$ state was reported in Ref. 2. No evidence is seen in the γ spectrum for any of the γ-decay branches of the 1140 keV state. The branching ratio to this level is less than 0.000 84% ($\log ft \geq 8.1$).

1514 and 1661 keV states. These states are populated by the β decay with $\log ft$ values which imply allowed β decays.[16] The observation of an allowed β decay to the 1514 keV state is proof of negative parity. This fact can be combined with the spin assignment of $\frac{5}{2}$ from Ref. 1 to conclude $J^\pi = \frac{5}{2}^-$ for the 1514 keV level. The observation of an allowed β-decay branch to the 1661 keV level is consistent with the assignment $J^\pi = \frac{3}{2}^-$ made in Ref. 1. We see no evidence of a ground state γ-decay branch from the 1661 keV state in agreement with Refs. 1 and 3 and in disagreement with Ref. 2.

1643 keV state. No β-decay branch to this state was observed. An upper limit of 0.000 23% was obtained for this branch ($\log ft \geq 8.2$). Although the nonobservation of this β-decay branch could result from hindrance, it suggests that the spins $\frac{3}{2}^-$, $\frac{5}{2}^-$, or $\frac{7}{2}^-$ are not likely. This information, when combined with the spin restriction of $J^\pi = \frac{1}{2}^-$, $\frac{3}{2}^-$, or $\frac{5}{2}^-$ from Ref. 1, suggests that $J^\pi = \frac{1}{2}^-$ for the 1643 keV state. $J^\pi = \frac{1}{2}^-$ is consistent with the predictictions of the strong coupling model.[1]

2182 keV state. A very weak γ ray is observed which would correspond to the 2182 → 91 keV transition. The two weaker decay modes of this state are not seen. The energies and relative strengths of these weak decay modes are taken from Ref. 1 and entered in Fig. 2 in parenthesis. The $\log ft$ of the transition to this state is consistent with the assignment $J^\pi = \frac{7}{2}^-$ of Ref. 1.

2235 keV state. The spin of this state was restricted to $\frac{3}{2}$, $\frac{5}{2}$, or $\frac{7}{2}$ in Ref. 1. The observation of a β-decay branch to this state is suggestive of negative parity, although the measured $\log ft$ value of 6.6 does not exclude positive parity.[16]

2309 keV state. The observation of a β-decay branch to this state is consistent with the assignment $J^\pi = \frac{3}{2}^-$ made in Ref. 1.

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