PHYSICAL REVIEW C VOLUME 31, NUMBER 4 APRIL 1985

β^+ decay of ^{47}Cr

T. W. Burrows, J. W. Olness, and D. E. Alburger
Brookhaven National Laboratory, Upton, New York 11973
(Received 7 January 1985)

The β^+ decay of ^{47}Cr ($J^\pi, T=\frac{3}{2}^-, \frac{1}{2}$) has been studied following its production by the ^{9}Be(^{40}Ca, 2n)^{47}Cr reaction at $E(^{40}\text{Ca})\approx 90$ MeV. In addition to the previously reported superallowed decay to the mirror state (i.e., the ^{47}V ground state), we observe a $(3.7\pm1.2)\%$ allowed β^+ branch to the $\frac{5}{2}^-$ state at 87 keV in ^{47}V. These two branches appear to dominate the decay of ^{47}Cr; an upper limit of less than 0.5% is set on possible γ rays, other than the 87-keV γ ray, in the range of 15 to 2800 keV. Measurement of the time decay of the 87-keV γ ray establishes a value of $T_{1/2}=508\pm10$ ms for the ^{47}Cr half-life which is in significant disagreement with two previously reported values. The present work utilized Ge spectroscopy and a He-jet system for transport of the beam-induced radioactivity, as opposed to previous measurements which used a plastic scintillator to detect positrons and either a He-jet chopper or a slow beam-pulsing system. A summary of decay data for the complete $f_{7/2}$ shell series of mirror nuclei is also presented.

I. INTRODUCTION

The nuclide ^{47}Cr is a member of eight $T_Z=-\frac{1}{2}$ nuclei in the $f_{7/2}$ shell which decay predominantly by superallowed β decay to the ground states of their mirrors ($T_Z=\frac{1}{2}$). The half-lives of all eight members have been reported previously (see Table I), as were the masses.[1] Hornshøj *et al.*[2] determined the half-life of ^{47}Cr to be 452 ± 18 ms, while Edmiston *et al.*[3] obtained a value of 460.0 ± 1.5 ms. Both groups employed the ^{46}Ti(^{3}He,2n)^{47}Cr reaction at bombarding energies of 14 and 16 MeV, respectively, and obtained the half-life of the ^{47}Cr ground state by following the decay of the positron spectrum.

Since the techniques used by the two groups were so similar, it seemed useful to confirm this activity by a different production and detection technique. The nuclide ^{47}Cr was produced by the ^{9}Be(^{40}Ca,2n)^{47}Cr reaction. A He-jet system was employed and the half-life of ^{47}Cr was obtained by following the decay of the 87-keV gamma from the first-excited $\frac{5}{2}^-$ state in ^{47}V. It should be noted here that Hornshøj *et al.*[2] did search for gammas with the appropriate half-life but did not observe any, leading them to set a limit of $<8\%$ decay to this state. A description of the experiment and the data analysis follows in the next section. The half-life of ^{47}Cr was determined to be 508 ± 10 ms and the allowed branch to the 87-keV, $\frac{5}{2}^-$ state was estimated to be $(3.7\pm1.2)\%$. The discrepancy

TABLE I. Superallowed β^+ decays in the $f_{7/2}$ shell.

Nucleus	$J^{\pi\,a}$	$T_{1/2}$ (ms)[a]	$I(\beta^++\epsilon)$ (%)[a,b]	$T_{1/2}$ and $I(\beta^++\epsilon)$ ref.	Q (keV)[c]	logft[d]	$\lvert\langle\sigma\tau\rangle\rvert$[e]
^{41}Sc	$\frac{7}{2}^-$	596.3 ± 1.7	(100)		6495.0 ± 1.0	3.453 ± 0.001	0.863 ± 0.009
^{43}Ti	$\frac{7}{2}^-$	513 ± 8	(100)		6868 ± 7	3.513 ± 0.007	0.749 ± 0.017
^{45}V	$\frac{7}{2}^-$	539 ± 18	95.7 ± 1.5		7132 ± 17	3.636 ± 0.017	0.512 ± 0.036
^{47}Cr	$\frac{3}{2}^-$	508 ± 10	96.3 ± 1.2	Present	7451 ± 14	3.705 ± 0.011	0.359 ± 0.029
^{49}Mn	$\frac{5}{2}^-$	384 ± 17	93.6 ± 2.6	17	7718 ± 24	3.671 ± 0.024	0.437 ± 0.054
^{51}Fe	$\frac{5}{2}^-$	310 ± 5	95.0 ± 1.3	13	8022 ± 15	3.655 ± 0.010	0.471 ± 0.023
^{53}Co	$(\frac{7}{2}^-)$	262 ± 25	(100)	17	8304 ± 18	3.634 ± 0.042	0.516 ± 0.086
^{55}Ni	$(\frac{7}{2}^-)$	208 ± 5	(100)	18	8696 ± 11	3.634 ± 0.011	0.514 ± 0.024

[a]From Refs. 10—12, except as noted. See these references for the data on which the evaluations were based.
[b]Values in parentheses were estimated. For ^{41}Sc and ^{55}Ni, the first state which may be populated by allowed decay is near 2.5 MeV; therefore 100% ground-state decay appears very probable.
[c]From Ref. 14.
[d]Calculated with the aid of the computer program described in Ref. 15.
[e]Calculated using the procedures and constants described in Ref. 16. The allowed approximation and the free-neutron axial vector coupling constant $R=1.237\pm0.008$ were assumed.

($\sim 5\sigma$) between our lifetime measurement and the previously reported results is discussed in Sec. III. A review of the decay parameters of the eight members of the $T_Z = -\frac{1}{2}$ multiplet is also given in that section.

II. EXPERIMENT AND RESULTS

The He-jet transfer system described previously[4,5] was used to study the radioactive decay of ^{47}Cr following its formation via the ^{9}Be(^{40}Ca,2n)^{47}Cr reaction. The fusion-evaporation reaction was initiated by bombarding a 2.35-mg/cm^2 thick target of ^{9}Be with a 120-MeV beam of ^{40}Ca ions. The kinematics of the "inverse" reaction ensures the $A \approx 47$ reaction products are constrained to a forward cone, and the collection process is, therefore, relatively efficient. The 0.0125-mm thick ^{9}Be target served as the entrance window to a cylindrical helium-filled chamber 7 cm long $\times 1.4$ cm diameter, in which the reaction products emerging from the Be foil were thermalized in a mixture of helium and water-alcohol vapor. The ^{40}Ca beam was stopped in a tantalum disk placed at the far end of the chamber.

The chamber was supplied at a (static) pressure of 1.3 atm by ^{4}He which had been passed through a water-alcohol bath. Thermalized reaction products, presumably attached to complex water-alcohol molecules, were pumped continuously through 1.67-mm inside diameter capillary tubing to a counting location some 6 m distant, on the far side of a concrete wall, where they were deposited on a Mylar collection tape. At periodic intervals the collection tape was moved precisely 30.5 cm, bringing the collected radioactivity to a lead-shielded region where the γ activity was measured with Ge(Li) and Ge detectors. The entire bombard/transport/count sequence was controlled by a timer-programmer[6] which also routed the detector spectra according to preselected counting intervals.

Under the experimental conditions described above, the ^{40}Ca interaction energy at the midpoint of the ^{9}Be target was ≈ 90 MeV: Resultant ^{47}Cr ions then emerged from the ^{9}Be foil with an energy of ≈ 35 MeV to be finally thermalized ≈ 2–4 cm into the helium-filled cell. In preliminary measurements the helium input pressure was varied from 1.15 to 1.5 atm, with maximum transfer yield for short-lived activities near ≈ 1.3 atm. Further tests indicated the collection efficiency using water-alcohol vapor was ≈ 20 times more efficient than that obtained with an oil-vapor mixture.

Figure 1 shows a portion of the γ-ray spectrum measured under the following conditions, where the indicated times (t) in seconds refer to the time ($t = 0$) at which the Mylar tape with its collected radioactivity was moved to the detector site:

$t = 0$,	start cycle;
$0 \le t \le 0.1$ s,	wait;
$0.1 \le t \le 2.5$ s,	store eight spectra (0.3 s each);
$2.5 \le t \le 2.6$ s,	reset to start.

During this 2.6-s cycle time a new source was being collected. The results shown correspond to a run of 4.2 h, or $\approx 6 \times 10^3$ cycles, at a ^{40}Ca beam current of 4 (particle) nA.

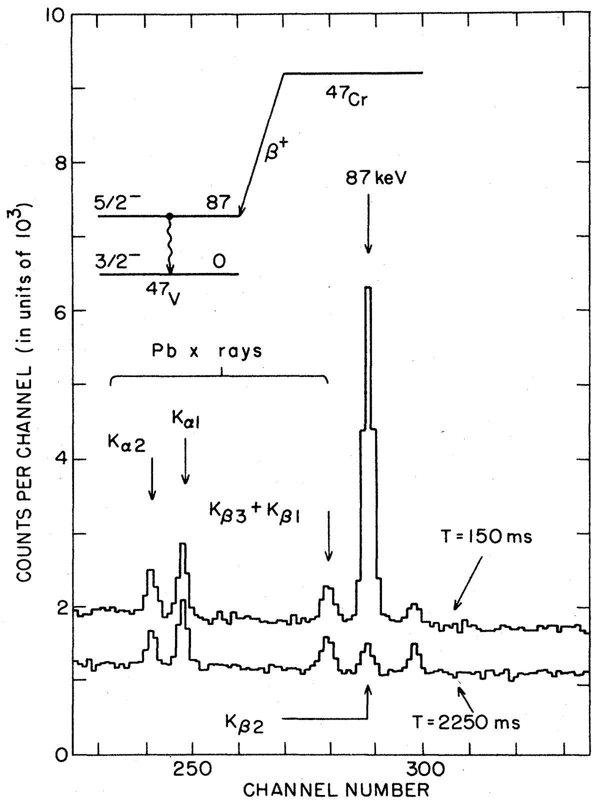

FIG. 1. Portions of planar Ge (intrinsic) detector spectrum recorded during the first ($T = 150$ ms) and last ($T = 2250$ ms) time bins of the count cycle. The inset shows the relevant portion of the ^{47}Cr(β^+)^{47}V decay scheme.

The data of Fig. 1 were measured with the planar Ge (intrinsic) detector, which viewed the radioactivity through a thin beryllium window. These two spectra were recorded during the first ($T = 150$ ms) and last ($T = 2250$ ms) time bins of the count cycle, where T is the average of the time interval measured relative to the start of the count cycle. The 87-keV γ ray associated with the decay ^{47}Cr is clearly evident, as are also K_β and K_α lines of Pb. These data were fitted as a sum of Gaussian peaks superimposed on a smooth background, in order to determine accurate peak areas. The results were then converted to relative intensities, using an efficiency curve (ϵ_γ vs E_γ) determined in a separate measurement with a ^{133}Ba source placed on the Mylar tape so as to duplicate the experimental geometry used for Fig. 1. In this way the intensity of the unresolved 87.3-keV $K_{\beta 2}$ line could be calculated exactly as 30% of the net $K_{\beta 3} + K_{\beta 1}$ intensity. Figure 2(a) shows the time dependence of the 87-keV ^{47}V line, after the small $K_{\beta 2}$ contribution has been subtracted. The data are fitted very well for a single decay half-life of $T_{1/2} = 510 \pm 11$ ms.

In order to extend the measurement over a longer time interval, the count sequence was altered to the following:

6×0.4 s bins,
1.0 s wait,
2×0.4 s bins.

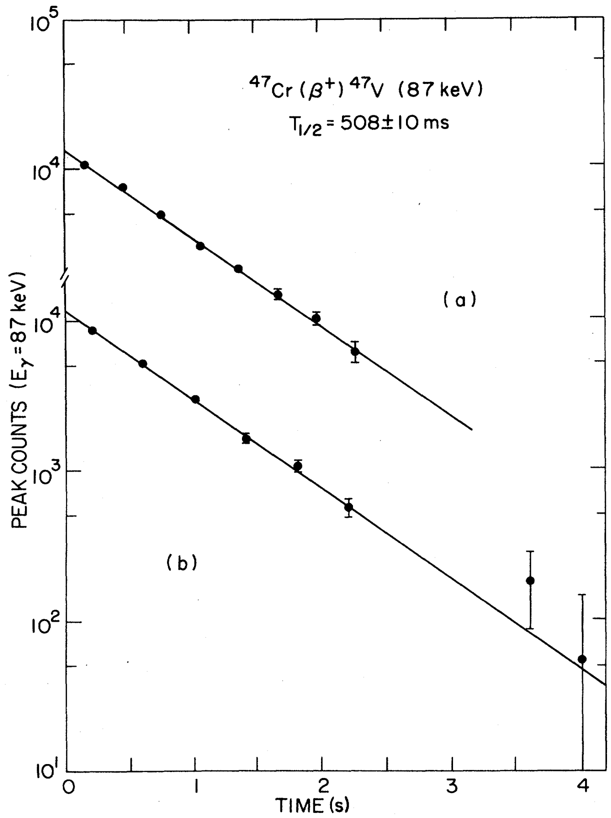

FIG. 2. Time dependence of the 87-keV gamma from ^{47}Cr β^+ decay for a 2.6-s cycle time. (b) Time dependence of the 87-keV gamma from ^{47}Cr β^+ decay for a 4.4-s cycle time.

The resultant data, shown in Fig. 2(b), illustrate the decay of the 87-keV line over two decades of intensity variation, indicating clearly that background is not a problem. The half-life deduced from the data is $T_{1/2}=506\pm14$ ms. The results of the two measurements are in excellent agreement, and we adopt the weighted mean value $T_{1/2}=508\pm10$ ms. In the quoted uncertainties we have allowed for a possible 1.5% systematic uncertainty due to dead time or other effects.

The plot of Fig. 1 shows only the region $68\leq E_\gamma\leq100$ keV. Examination of the spectra over the range $15\leq E_\gamma\leq550$ keV disclosed no additional lines (other than 511 keV) with decay half-lives in the region of 508 ms. The Ge(Li) spectrum for $50\leq E_\gamma\leq2800$ keV was similarly devoid of interest. Thus, we conclude that the ^{47}Cr β^+ proceeds predominantly to the 87-keV excited state and to the ground state of ^{47}V. An upper limit of $<0.5\%$ is set on transitions involving alternate decay routes.

The time decay data for the 511-keV line, resulting from β^+ annihilation, was well characterized by a 508-ms component superimposed on a flat background ($T_{1/2}\sim\infty$). These data were fitted to determine the intensity of 511-keV annihilation γ rays associated with the 508-ms ^{47}Cr decay, relative to the 87-keV intensity, using for this purpose the efficiency calibration established previously. After allowing for the fact that there are two 511-keV γ rays for each annihilation, we deduce a branching ratio for β^+ decay to the ^{47}V 87-keV level of $(3.7\pm1.2)\%$. The correction for internal conversion of the 87-keV gamma was negligible. The quoted uncertainty has been increased over the purely statistical uncertainty in order to allow for the fact that the site of the β^+ annihilation is not restricted to the ^{47}Cr source position.

III. DISCUSSION

The discrepancy between our half-life measurement of 508 ± 10 ms and the previous results of 452 ± 18 ms (Ref. 2) and 460.0 ± 1.5 ms (Ref. 3) has been investigated. While the ^{9}Be(^{40}Ca,2n)^{47}Cr fusion-evaporation reaction used in the present work is less selective than the ^{46}Ti(^{3}He,2n)^{47}Cr reaction employed by Hornshøj *et al.*[2] and Edmiston *et al.*,[3] the detection technique (i.e., observation of gammas associated with the decay of the product nuclei) is appreciably more selective. This latter advantage is substantiated in two ways. First, there are no known γ ray[7] energies and half-lives in the vicinity of 87 keV and 500 ms which could be produced by ^{40}Ca on ^{9}Be. Second, we followed the decay of the 87-keV line to the point where only the $K_{\beta2}$ Pb x ray was present and observed no evidence of another contaminant line.

The work of Hornshøj *et al.*[2] and Edmiston *et al.*[3] both relied on the ^{46}Ti(^{3}He,2n)^{47}Cr reaction and positron detection. The major short-lived contaminant with this combination of target and projectile would be ^{46}V with $T_{1/2}=422.33\pm0.20$ ms.[8] Both experiments intentionally discriminated against the (^{3}He,nd) channel (threshold energy, $E_{\rm th}=14.2$ MeV) by setting the incident beam energy at 14 and 16 MeV, respectively. However, these energies would allow the (^{3}He,t) channel ($E_{\rm th}=7.53$ MeV) to contribute to the production of ^{46}V. In a preliminary time-of-flight mass spectra measurement, Edmiston *et al.*[9] estimated the production of $A=46$ products to be less than 5% of that for $A=47$ products; however, their count rate was so low that they were unable to ascertain the exact isotopes produced.

Determination of lifetimes by means of positron counting must be done with great care since the technique is extremely nonselective. In the case of the data of Hornshøj *et al.*[2] we note that they have a relatively high background (≈200 counts/100 ms maximum). As a test, we calculated a two-parameter decay curve consisting of 90% $T_{1/2}=508$ ms and 10% $T_{1/2}=422$ ms, corresponding to a mixture of ^{47}Cr and ^{46}V, and found that this calculation reproduced the data of Hornshøj *et al.*[2] within uncertainties.

Äystö *et al.*[13] have recently measured the decay of ^{51}Fe and ^{55}Ni produced by bombardment of ^{54}Fe and $^{50}Cr_2O_3$ targets with 27-MeV ^{3}He ions. Their half-life measurements employed an ion-guide, on-line isotope separator with a β-ray telescope used to detect the radioactive decay. Their results were 310 ± 5 and 208 ± 5 ms for the ^{51}Fe and ^{55}Ni half-lives, respectively. Note that these values are significantly longer than the half-lives of 245 ± 7 and 189 ± 5 ms values obtained by Hornshøj *et al.*[2] Äystö *et al.*[13] also observed the 237.4-keV gamma deexciting the first-excited state of ^{51}Mn with both the isotope separator and with a He-jet system. The He-jet measurement resulted in a ^{51}Fe half-life of 320 ± 15 ms, agreeing with their positron measurement.

We, therefore, conclude on the basis of the above discussion that there is most probably a systematic error in the work of Hornshøj *et al.*[2] and that our half-life measurement for ^{47}Cr and those of Äystö *et al.*[13] for ^{51}Fe and ^{55}Ni should be preferred.

Table I summarizes the decay data currently available for the complete $f_{7/2}$-shell series of mirror nuclei. Also included in this table are the Gamow-Teller matrix elements extracted from the decay data. With the exception of ^{49}Mn and ^{53}Co, the data on the eight members of the $T_Z=-\frac{1}{2}$ multiplet appear to be sufficiently precise to allow useful comparisons with theory.

This research was supported by the U.S. Department of Energy, Division of Basic Energy Sciences, under Contract No. DE-AC02-76CH00016.

[1]D. Mueller, E. Kashy, W. Benenson, and H. Nann, Phys. Rev. C **12**, 51 (1975).

[2]P. Hornshøj, L. Højsholt-Poulsen, and N. Rud, Nucl. Phys. **A288**, 429 (1977).

[3]M. E. Edmiston, R. A. Warner, Wm. C. McHarris, and W. H. Kelly, Nucl. Instrum. Methods **141**, 315 (1977).

[4]D. E. Alburger and T. G. Robinson, Nucl. Instrum. Methods **164**, 507 (1979).

[5]C. J. Lister, P. E. Haustein, D. E. Alburger, and J. W. Olness, Phys. Rev. C **24**, 260 (1981).

[6]G. E. Schwender, D. R. Goosman, and K. W. Jones, Rev. Sci. Instrum. **43**, 832 (1972).

[7]U. Reus and W. Westmeier, At. Data Nucl. Data Tables **29**, 1 (1983).

[8]R. L. Auble, Nucl. Data Sheets **24**, 1 (1978).

[9]M. D. Edmiston, R. A. Warner, W. C. McHarris, and W. H. Kelly, in Proceedings of the Third International Conference on Nuclei Far From Stability, Cargèse, France, CERN Report CERN-76-13, 1976, p. 258.

[10]P. M. Endt and C. van der Leun, Nucl. Phys. **A310**, 1 (1978).

[11]T. W. Burrows, Nucl. Data Sheets **40**, 149 (1983); M. L. Halbert, *ibid.* **22**, 59 (1977); **24**, 175 (1978); R. L. Auble, *ibid.* **23**, 163 (1978); **21**, 323 (1977); D. C. Kocher, *ibid.* **18**, 463 (1976).

[12]*Table of Isotopes,* 7th ed., edited by C. M. Lederer and V. S. Shirley (Wiley, New York, 1978).

[13]J. Äystö, J. Ärje, V. Koponen, P. Taskinen, H. Hyvönen, A. Hautojärvi, and K. Vierinen, Phys. Lett. **138B**, 369 (1984).

[14]A. H. Wapstra and G. Audi, private communication.

[15]N. B. Gove and M. J. Martin, Nucl. Data Tables **A10**, 205 (1971).

[16]S. Raman, C. A. Houser, T. A. Walkiewicz, and I. S. Towner, At. Data Nucl. Data Tables **21**, 567 (1978).

[17]J. C. Hardy, H. Schmeing, E. Hagberg, W. Perry, J. Wills, E. T. H. Clifford, V. Koslowsky, I. S. Towner, J. Camplan, B. Rosenbaum, R. Kirchner, and H. Evans, Phys. Lett. **91B**, 207 (1980).

[18]S. Kochan, B. Rosner, I. Tserruya, and P. Kalish, Nucl. Phys. **A204**, 185 (1973).