Half-lives of ^{51}Cr, ^{48}Cr, and ^{48}V†

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The half-lives of ^{51}Cr, ^{48}Cr, and ^{48}V have been determined by following the decay of the isotopes for six to ten half-lives. The half-lives were obtained by a least-squares weighted fit to the data. The half-life of ^{48}Cr ($T_{1/2}$ = 21.56 ± 0.03 h) is considerably lower than previous measurements.

[RADIOACTIVITY ^{51}Cr, ^{48}Cr, ^{48}V; measured $T_{1/2}$.]

I. INTRODUCTION

Measurements of the mass effect in diffusion require highly accurate values of the half-lives of the radioisotopes used as tracers.[1] In principle, the mass effect in chromium self-diffusion could be measured using the isotopes ^{51}Cr and ^{48}Cr, but the uncertainties of the values of the half-life ($T_{1/2}$) of ^{48}Cr [2-5] are too great. The measurement of $T_{1/2}(^{48}\mathrm{Cr})$ is complicated by both the growth of the radioactive daughter ^{48}V and the presence of the ^{51}Cr isotope created in the ^{48}Cr production process. Most of the earlier measurements gave $T_{1/2}(^{51}\mathrm{Cr})$ ~ 27.8 days,[5-11] with an error >0.5%. A closer search of the literature, after the present work was completed, showed two measurements with small error and close agreement ($T_{1/2}$ = 27.701 ± 0.006,[12] $T_{1/2}$ = 27.704 ± 0.007 [13]). Most of the reported measurements of $T_{1/2}(^{48}\mathrm{V})$ gave values of about 16.2 ± 0.2 days,[4,5,14-16] although values below 16 days were also reported.[3,10] The most accurate value of $T_{1/2}(^{48}\mathrm{V})$ = 15.971 ± 0.004 days[11] was reported after the present work had been initiated. We have made an accurate measurement of $T_{1/2}$ for the isotopes ^{51}Cr, ^{48}V, and ^{48}Cr.

II. RADIOISOTOPES

The ^{51}Cr isotope was obtained from International Chemical and Nuclear Corporation in the form of chromic chloride dissolved in 0.5 *N* HCl. The isotope was produced by the process $^{50}\mathrm{Cr}(n,\gamma)^{51}\mathrm{Cr}$. Analysis of the γ spectrum using a Ge-Li dete tor showed no detectable radioactive impurities. The decay of two samples was followed for six months using a 3 by 3 in. well-type NaI(Tl) scintillation counter with a low-level discriminator set at ~0.25 MeV.

The ^{48}V isotope was obtained from International Chemical and Nuclear Corporation in the form of vanadium chloride dissolved in 0.1 *N* HCl. The isotope was produced by the process $^{48}\mathrm{Ti}(p,n)^{48}\mathrm{V}$ and subsequent chemical separation. Analysis of the γ spectrum using a Ge-Li detector showed no detectable radioactive impurities. The decay of two samples was followed for six months using a 3 by 3 in. well-type NaI(Tl) scintillation counter with a low-level discriminator set at ~0.25 MeV. The discriminator level setting ensured that any ^{49}V isotope present would not be counted.

The ^{48}Cr isotope was produced by the process $^{48}\mathrm{Ti}(^3\mathrm{He},3n)^{48}\mathrm{Cr}$ using the cyclotron at Argonne National Laboratory. The irradiated titanium foil was dissolved in 4 *M* H_2SO_4 and oxidized with concentrated nitric acid. To ensure oxidation of the chromium to the dichromate, sodium bismuthate is added to excess. The dichromate is extracted with tributylphosphate, and the vanadium removed by scrubbing with 1 *M* HCl. At this point, referred to as zero time, the ^{48}Cr isotope contained zero amount of the ^{48}V daughter product. The chromium was then stripped from the organic phase by reduction with 6% sulfurous acid in 1 *M* HCl. After the chemical separation, an analysis using a Ge-Li detector showed only the isotopes ^{48}Cr, ^{51}Cr, and ^{48}V. The ^{48}Cr isotope was made on three separate occasions, and the decay of four samples was followed over periods of 18 to 32 days. The decay was followed using a 3 by 3 in. well-type NaI(Tl) scintillation counter with a low-level discriminator set at ~0.09 MeV.

III. TREATMENT OF DATA

The scintillation counter dead times were in the range of 1.5 ± 0.15 μsec. At zero time all isotope samples counted ~10^6 cpm (counts per minute). Count rates were corrected for dead time and background (300–500 cpm depending on the discriminator level setting). At least 10^5 counts over background were obtained for each of the approximately 50 times the samples were counted. The counts were considered to start at $t + \frac{1}{2}T$, where t is the count start time measured to 1 sec on an electric clock, and T is the length of the count time measured using an electronic timer. The accuracy of the electric clock was checked against Universal Coordinated Time several times during the span of the six-month counting period.

TABLE I. Half-life values.

Nuclide	Half-life	Number of half-lives followed	Reference
^{51}Cr	27.701 ± 0.006 days	Not known	12
^{51}Cr	27.704 ± 0.007 days	13.6	13
^{51}Cr	27.703 ± 0.008 days	6.6	Present work
^{48}V	15.971 ± 0.004 days	<10	11
^{48}V	15.976 ± 0.003 days	11.5	Present work
^{48}Cr	22.96 ± 0.05 h	2–5	5
^{48}Cr	21.56 ± 0.03 h	20–35	Present work

The data were fitted using a least-squares method with each datum point weighted according to the inverse sum of the variances of the count rate, background, and dead time. The ^{51}Cr and ^{48}V data were fitted to a single exponential equation, and the deviations about the regression line were random in each case. The ^{48}Cr data were fitted to a three-exponential equation of the form

$$Y = A\left(\frac{\lambda_a \lambda_b}{\lambda_b - \lambda_a} - \lambda_a\right) e^{-\lambda_a t} - A\left(\frac{\lambda_a \lambda_b}{\lambda_b - \lambda_a}\right) e^{-\lambda_b t} + Be^{-\lambda_c t}, \quad (1)$$

where Y is the count rate at time t, and λ_a, λ_b, and λ_c are the decay constants of ^{48}Cr, ^{48}V, and ^{51}Cr, respectively. The ^{48}Cr data will follow the form of Eq. (1) only when, at a given zero time, no ^{48}V isotope is present. In this particular case, A is the initial count rate of ^{48}Cr at zero time, and B is the count rate of ^{51}Cr at zero time. In the least-squares fitting procedure, the values of λ_b and λ_c were held fixed at the values found in the present work. The most accurate value of λ_a was determined from the exponential term; however, the form of Eq. (1) allows a determination of λ_a from a sum of the first two preexponential terms. The values of λ_a obtained in this manner are dependent on the accuracy with which the zero time is known. The mean value of the half-life obtained from the preexponential terms was 21.4 ± 0.8 h, and agrees, within experimental error, with the value obtained from the exponent (Table I). The value of B obtained from the fitting procedure showed that immediately following irradiation the ^{51}Cr counts were less than 0.2% of the ^{48}Cr counts.

The values of the half-lives obtained for ^{51}Cr, ^{48}V, and ^{48}Cr are shown in Table I and are compared with the most accurate of the previous measurements. Our measurements are in quite close agreement with the values of $T_{1/2}(^{51}\mathrm{Cr})$ and $T_{1/2}(^{48}\mathrm{V})$. The present work suggests that $T_{1/2}(^{48}\mathrm{Cr})$ is considerably lower than most previous measurements.[2-5] The work of Karol and Miller[17] yielded a value of $T_{1/2}(^{48}\mathrm{Cr}) = 22.0$ h. An error in this value was not quoted but the value is also much lower than previous measurements.

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