# $^{50}$V half-life limit

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Half-life limits $T_{1/2}(\beta^-) > 7.0 \times 10^{17}$ yr and $T_{1/2}(\mathrm{EC}) > 8.8 \times 10^{17}$ yr have been deduced for $^{50}$V from Ge(Li) spectra.

[RADIOACTIVITY $^{50}$V, deduced $\beta^-$, EC half-life limits, Ge(Li) detector.]

According to nuclear systematics for isobars, $^{50}$V is expected to be unstable against $\beta$ decay. So far this decay has not been observed. The probable decay modes of the $J^\pi = 6^+$ ground state of $^{50}$V (Fig. 1) are by negatron emission and electron capture to the first excited states of $^{50}$Cr and $^{50}$Ti, respectively, with ($\Delta l = 4$, no) transitions. The $^{50}$Cr and $^{50}$Ti states then promptly decay by $\gamma$-ray emission thus making feasible the search for the $^{50}$V $\beta$ radioactivity via $\gamma$ radiations of daughter nuclei. Several attempts have been made to detect these $\gamma$ rays with NaI spectrometers.[1,2] The usual method has been to obtain $^{50}$V activity limits (or values in earlier papers) by subtracting a background spectrum from the $^{50}$V spectrum. However, the difficulties in obtaining a background spectrum which corresponds exactly to $^{50}$V counting conditions, and the presence of unresolved activities from $^{40}$K and heavy radioactive nuclei, have made spectral interpretation a delicate problem. From extrapolated log$ft$ values, it appeared possible that the $^{50}$V daughter radiations could be detected in Ge(Li) measurements. Although the Ge(Li) detector is much less efficient than NaI, considerable simplicity is gained in its use. Accordingly we have made measurements on a large sample of natural vanadium, which contains $^{50}$V, with a well-shielded Ge(Li) detector.

4 kg of high purity natural vanadium in the form of metallic chips were counted for a total of 1173 h with a 70 cm$^3$ Ge(Li) spectrometer. To reduce the background radiation, the detector and cryostat were placed inside a counting cave having 12 cm thick iron walls on all sides. The vanadium was placed in a plastic container which fitted over the detector head. An additional shielding composed of a thickness of 3 cm of mercury was placed around the vanadium on all sides except that facing the cryostat. The integrated background activity for $E_\gamma \leq 2$ MeV was reduced a factor $\approx 60$ by the iron and mercury.

It was apparent that $\gamma$ rays from naturally occurring heavy nuclides, fallout, and $^{40}$K were still present in the spectra. Some of these interfere with the measurements in that they appear at or near the energies of the $^{50}$V daughter radiations sought. Most or all of the contamination was not contained in the vanadium sample used, since the strength of the contamination peaks observed in a 276 h background count corresponded to those in the vanadium count. (Preliminary measurements of kg quantities of other vanadium samples showed levels of contamination, which though extremely low, were enough to render this experiment impossible.)

Repeated counts of 23 h duration were taken. Between each measurement, the system gains were checked and occasionally adjusted as necessary. For short measurements with a source, the spectrometer resolution was 2.6 keV for $^{60}$Co. The resolution of the 23 h spectra was $\approx 4$ keV for the energy region 500–1500 keV. The spectrum obtained by summing all the individual measurements showed a 5 keV resolution.

The relative efficiency calibration for $\gamma$ rays of $245 \leq E \leq 1408$ keV was made by later counting a solution of $^{152}$Eu in the chamber used for the vanadium. The absolute efficiency calibration was made with a solution of KCl of known concentration for which the $^{40}$K activity was known. No correction was applied for the difference of less than 10% in the $\gamma$-ray self-absorption between the calibra-

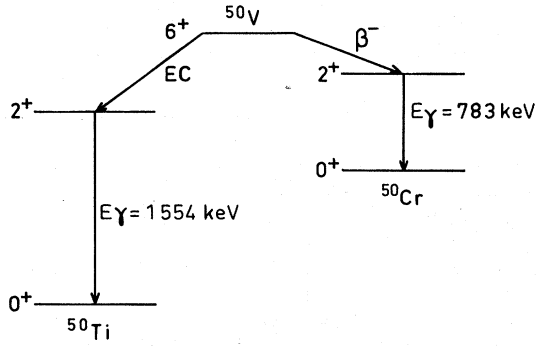


FIG. 1. Diagram of the probable decay modes of $^{50}$V.

tion measurements and the measurement on the vanadium.

The accuracy of the catalogued[3] energies of the first excited states in $^{50}$Cr and $^{50}$Ti, 783 and 1554 keV, respectively, was checked by proton inelastic scattering on targets enriched in these nuclei.

*$E_\gamma$ = 1554 keV.* This energy region of the summed spectrum is shown in an insert of Fig. 2. For $1545 \leq E_\gamma \leq 1565$, $\gamma$ rays from $^{234}$Pa$^m$ ($E_\gamma = 1554$ keV, $15 \pm 1$ counts), $^{228}$Ac ($E_\gamma = 1557$ keV, $16 \pm 3$ counts), and possibly $^{50}$V are present. The number of counts due to the heavy isotopes was deduced from isolated peaks occurring in other parts of the spectrum, the diode efficiency, and with the aid of energy and branching ratio compilations.[3-5] Fits with Gaussian-shaped peaks on a linear background were made over a restricted energy range. In the smooth curve shown in the insert of Fig. 2 activities of $13 \pm 7$ and $17 \pm 7$ counts were calculated for the $^{234}$Pa$^m$ and $^{228}$Ac peaks, respectively. The normalized $\chi^2$ depended somewhat on the limits taken for the fit, but generally the best fits (obtained with reasonable full width at half maximum and proper energies) were those having approximately the number of counts given above for $^{234}$Pa$^m$ and $^{228}$Ac. The result is that any activity due to $^{50}$V is less than about 20 counts. With a $^{50}$V abundance of 0.25% (Ref. 5), this corresponds to $T_{1/2}(\mathrm{EC}) > 8.8 \times 10^{17}$ yr for decay for the first excited level of $^{50}$Ti.

*$E_\gamma$ = 783 keV.* This region of the summed spectrum is likewise shown in Fig. 2. Six contaminant $\gamma$ rays are present within a few keV of the energy of the $^{50}$Cr $\gamma$ ray, the strongest being from $^{234}$Pa$^m$ ($E_\gamma = 786$ keV, $193 \pm 11$ counts), $^{214}$Bi ($E_\gamma = 787$ keV, $147 \pm 16$ counts), and $^{212}$Bi ($E_\gamma = 785$ keV, $178 \pm 25$ counts) as deduced by the procedure outlined in the last paragraph. By taking the number of counts deduced for each of the contaminant peaks over the restricted range $777 \leq E_\gamma \leq 792$, and folding in the detector resolution, the shape of the spectrum was calculated. Best fits between the data and this shape superimposed on an adjustable flat background were made. The evolution of the fits was then studied as a function of the number of counts in an additional peak centered around 783 keV. In some cases, fits could be improved with a small contribution around 783 keV, but evaluation of the $^{50}$Cr activity by this procedure is not reliable because this activity can also be due to statistical fluctuations in known spectral components. If such an analysis cannot be used to assign a definite activity to $^{50}$Cr, one can give an approximate upper limit. Thus it appears that fewer than about 50 counts are attributable to $^{50}$V. This leads to $T_{1/2}(\beta^-) > 7.0 \times 10^{17}$ yr for decay to the first excited level of $^{50}$Cr.

The observed bump at 780 keV is evidently due to statistical fluctuations, as it does not match any reasonable assignment. The intensities of the peaks at 768 and 772 keV agree within statistical errors with intensities deduced for $^{234}$Pa$^m$, $^{214}$Bi,

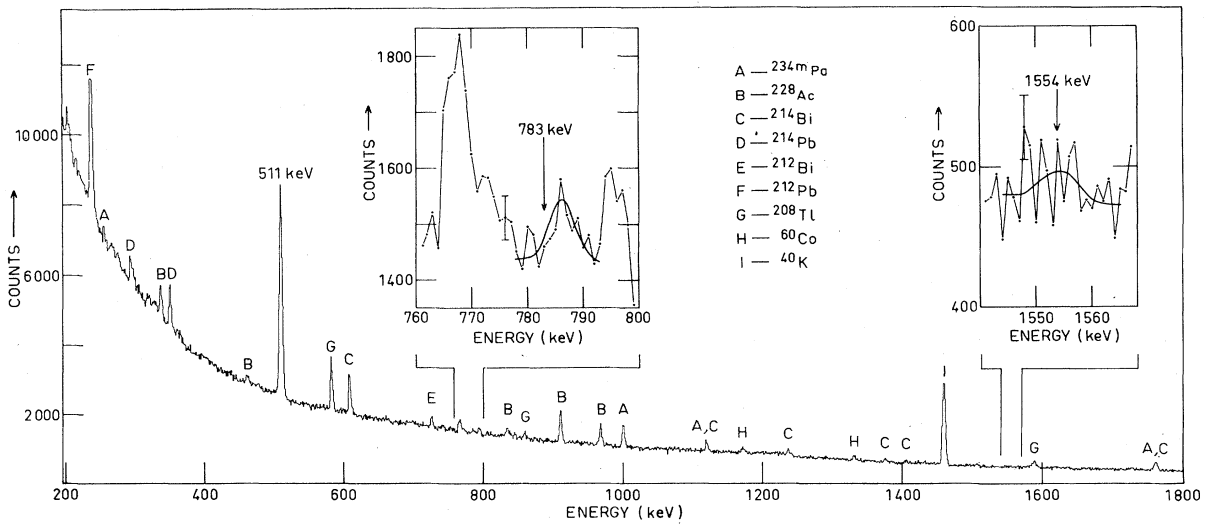


FIG. 2. Ge(Li) $\gamma$-ray spectrum of 4 kg of metallic vanadium for a total counting time of 1173 h. The insert in the left-hand part of the figure shows an expanded view of the region around the 783 keV $\gamma$ ray of the $^{50}$Cr daughter. The smooth curve is the fit of the spectral form calculated from deduced contaminant activities added to a flat background, with no activity included for $^{50}$Cr. The insert at the right is the expanded view of the region around the 1554 keV $\gamma$ ray of the $^{50}$Ti daughter. The smooth curve is the result of a fit with two Gaussian shaped peaks and a linear background.

and $^{228}$Ac from other peaks in the spectrum. The $^{228}$Ac peak at 795 keV agrees well with its deduced activity.

In the final analysis we give $^{50}$V half-lives of $>8.8\times10^{17}$ and $>7.0\times10^{17}$ yr for EC and $\beta^-$ decay, respectively. These limits are 10 times longer than those obtained from low background NaI measurements.[1] A better half-life determination would seem to be a major undertaking, involving especially the elimination of heavy element contaminations.

Values of $\log f_0 t(\beta^-)>24.2$ and $\log f_0 t(\mathrm{EC})>24.2$ can be deduced for $^{50}$V (Ref. 6). On the basis of single particle shell model $f_{7/2}$ to $f_{7/2}$ calculations, Morita's group[7] finds $T_{1/2}(\beta^-)=1.50\times10^{18}$ yr, or about twice the present limit. They are preparing calculations using more complex models which should have the effect of lengthening the calculated half-lives.

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