Radiative Orbital Electron Capture in Vanadium-49

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The x-radiation and the continuous electromagnetic radiation accompanying orbital electron capture in vanadium-49 have been studied by means of an argon-methane proportional counter and a well-type sodium iodide scintillation spectrometer. The observed pulse-height distribution was corrected for background, energy resolution, escape of degraded radiation from the crystal, gamma-ray detection and geometrical efficiency of the crystal, and absorption of the radiation between the source and detector. The transition energy of the V^{49} decay is 616 ± 10 kev, giving a total disintegration energy of 621 ± 10 kev. The half-life is measured as 327 ± 20 days, giving a $\log ft=6.2$, which is consistent with other allowed spectra with initial and final states in the $f_{7/2}$ shell.

THE assignment of a 600-day orbital electron capture activity to the mass-49 isotope of vanadium was made by Walke, Williams, and Evans[1] by means of a (d,n) reaction on titanium. No positrons or gamma rays were reported to accompany this activity. Subsequent assignment of a 635-day activity to this mass number was made by Hollander, Seaborg, and Perlman[2] based on an observation of an induced activity by Cork, Keller, and Stoddard,[3] who irradiated natural vanadium with neutrons. Gamma rays of 81- and 119-kev energy were observed to accompany this activity. This latter assignment is open to suspicion, for it assumed an $(n,2n)$ reaction on the 0.25% abundant isotope V^{50}. Since no chemical identification of the activity was made, there is a likelihood that it may have resulted from a reaction with an impurity in the vanadium. The present work was undertaken to examine further the nature of the decay of V^{49} and to gain additional information about the energy systematics in this region of mass number.

A target of titanium metal was bombarded with fifteen-Mev deuterons from the sixty-inch cyclotron of the Department of Terrestrial Magnetism, Carnegie Institution of Washington. The V^{49} was formed by a (d,n) reaction on Ti^{49}, the most abundant isotope of titanium. The target was allowed to stand for a period of four months to allow the 16-day V^{48} to decay. The vanadium was chemically separated from the titanium target as lead vanadate, the lead precipitated with H_2S, and finally a vanadium source prepared as V_2O_5.

The gamma-ray activity of the vanadium source was observed with a sodium iodide scintillation spectrometer at one-month intervals. The principal activity observed for approximately ten months after the bombardment was that due to the V^{48}.

A small portion of the source material was then mounted between one-mil Saran films and placed inside an argon-methane proportional counter spectrometer. Titanium x-rays were observed by taking a pulse-height spectrum using a linear pulse amplifier and a single-channel differential discriminator. By using the same counter, the decay of these x-rays was followed over a period of 160 days. The observed half-life was 327 ± 20 days. This value is in essential agreement with a value of 334 ± 20 days by Lyon,[4] whose results were published while this work was in progress.

The remainder of the vanadium was placed in a thin celluloid tube and placed inside the well of a sodium iodide scintillation spectrometer. This spectrometer consisted of a three- by three-inch cylindrical sodium iodide crystal with a three-quarter-inch well two inches deep along the axis of the crystal. The crystal was viewed by a three-inch photomultiplier tube followed by a linear pulse amplifier and a single-channel differential discriminator. The pulse-height spectrum of the weak continuous radiation accompanying orbital electron capture was obtained and corrected for background.

A number of other corrections to the observed spectrum were required in order to obtain the true spectrum. For the purpose of making these corrections, a number of characteristics of the complete sodium iodide scintillation spectrometer were measured. The pulse-height spectra of monoenergetic gamma-ray lines ranging from 73 to 1330 kev were measured. The resolution of the spectrometer in terms of full width at half-maximum for each line was determined and this information was used to correct the observed spectrum for the distortion due to the finite resolution of the detector. The correction method outlined by Owen and Primakoff[5] is valid for a spectrum of this type since the correction terms are very small.

These same spectra were used to determine the distribution of pulses resulting from a photon of any given energy. Since more detailed information was needed here, the experimental data were supplemented by the results of Monte Carlo calculations by Berger and Dogget[6] on the response of sodium iodide crystals to various energy photons. Their results were used to interpolate between the experimental points. One use of this

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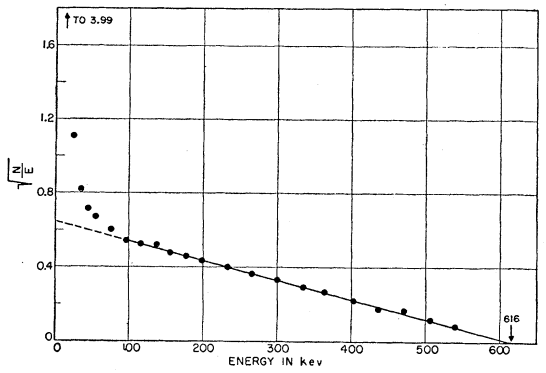

FIG. 1. "Fermi" plot of corrected experimental data in terms of the spectrum of Morrison and Schiff.

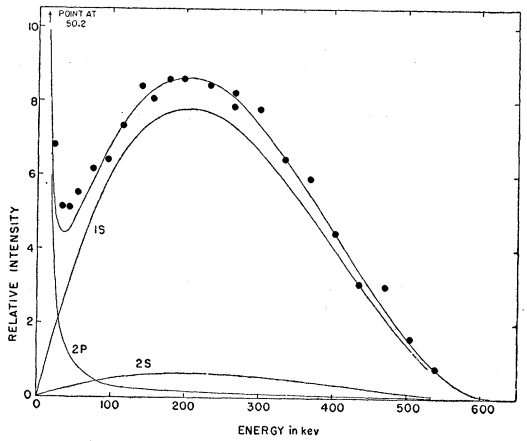

FIG. 2. Comparison of corrected experimental data with theoretical spectrum of Glauber and Martin.

information is to remove the contribution to the pulse-height distribution at lower energies due to the partial escape of energy from the crystal when a photon of higher energy has interacted with the crystal. This correction is made by dividing the observed pulse-height spectrum into equal pulse-height increments and then, starting with the highest pulse-height increment, determining the effect on the intensity in each lower increment.

A second correction uses the information to determine the fraction of the total pulse-height distribution that appears at the region of full pulse height. The observed pulse-height spectrum is divided point by point by this experimentally determined fraction. These corrections are similar to the ones employed by Lidén and Starfelt[7] except that the experimental pulse-height distributions are used numerically rather than analytically. The well-type crystal greatly reduces the contributions to the pulse-height spectrum in the region of the Compton edge and likewise nearly eliminates the effects due to K x-ray escape and backscattering.

The geometrical and detection efficiencies of the crystal were obtained by numerical integration using the mass absorption coefficients for photons in sodium iodide compiled by White.[8] The absorption of the primary radiation between the source and detector by the celluloid container and the aluminum wall surrounding the crystal was similarly computed. The excessive wall thickness of 30 mils of aluminum was undesirable since the corrections became quite appreciable below 15 kev. However, this thickness attenuated the x-radiation from the source by a very large factor and prevented its piling up with the time-coincident continuous spectrum.

Assuming that the higher energy portion of the spectrum may be reasonably well represented by the Morrison-Schiff[9] spectrum, i.e. $N=\text{const}E(1-E/E_{\max})^2$, one can make a "Fermi" analysis of the data by plotting $(N/E)^{\frac{1}{2}}$ *vs* E. Such an analysis is shown in Fig. 1. The upper energy limit of the spectrum is 616±10 kev. The total energy separation between V^{49} and Ti^{49} is obtained by adding to the spectrum end point the binding energy of the electrons in the K shell in titanium. This gives a mass difference of 621±10 kev and is in essential agreement with the value, 609±5 kev, as deduced from the (p,n) threshold measurement on Ti^{49} by Trail and Johnson.[10] Good agreement with the Morrison-Schiff spectrum is obtained down to about 100 kev, where the deviations become appreciable. A recent calculation of the radiative orbital electron capture process has been made by Glauber and Martin,[11] incorporating Coulomb and p-electron capture effects. A comparison of the corrected experimental data with the theoretical predictions is shown in Fig. 2. The experimental data have been normalized at the 200-kev point, the slope being zero there. The $1S$, $2S$, and $2P$ components are those from the theory of Glauber and Martin multiplied by the screening corrections calculated for each of these particular shells by Brysk and Rose.[12] The agreement is well within the probable error of the experimental points, except perhaps at the very lowest energy point where the corrections are quite appreciable.

No monoenergetic gamma radiation is present to an amount greater than one part in 10^5 of the total disintegrations. Combining the half-life value of 327 days with the transition energy of 616 kev, one obtains a $\log ft=6.20$.

Recent work by Nussbaum *et al.*[13] on the decay of

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Cr^{49} would favor a ground-state spin assignment of $f_{7/2}$ for V^{49}. On the other hand, Flowers,[14] on the basis of theoretical considerations of nuclei having 23 or 25 odd nucleons, would favor a 5/2, minus-parity state, in analogy with Ti^{47}. The ground level of Ti^{49} has been measured to be in a $f_{7/2}$ state. From the experimental evidence offered above, it is impossible to decide whether the ground state of V^{49} is a 5/2 minus or 7/2 minus state. However, the $\log ft = 6.20$ is consistent with other allowed transitions in this region of mass number where the transitions occur between levels in $f_{7/2}$ states.[15]

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Inelastic Nuclear Scattering of Photons by Au^{197}†*

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A lower limit of the total inelastic nuclear photon scattering cross section of Au was determined as a function of energy by measuring the yield of the reaction $Au^{197}(\gamma,\gamma')Au^{197m}$ (7.5 sec) as a function of betatron energy. The use of pneumatic transfer and of NaI-counters in good geometry with 16-gram gold disks as samples enabled one to obtain good counting statistics and detailed decay curves at all betatron energies between 4 and 24 Mev. It is found that the cross section falls off steeply as soon as the competition from the (γ,n) reaction becomes possible. The maximum cross section of about 3.5 mb is reached at (7.8 ± 0.2) Mev. This disagrees with earlier work of Cameron and Katz but corresponds qualitatively to the same behavior as exhibited by $In^{115}(\gamma,\gamma')In^{115m}$ in the recent work of Burkhardt *et al.* Our results indicate a second peak of the cross section at about 15 Mev, where the giant resonance has its maximum, in agreement with recent work of Hayward and Fuller on elastic scattering from gold.

These results are compared with the predictions based on the statistical model. It is shown that they can be interpreted most naturally by assuming that below 12 Mev the width for γ emission is of the order of Weisskopf's estimate for Γ_{E2} or Γ_{M1}. Available experimental data on (γ,γ') reactions in other elements are reconsidered in the light of this conclusion.

I. INTRODUCTION

IN recent years, the method by which the Notre Dame group[1,2] excited isomeric states in stable nuclei has found increasing application for the study of (γ,γ') reactions, i.e., of inelastic nuclear photon scattering processes, in the region of the giant resonance in the nuclear absorption of γ rays. In this method, an element having a nuclear isomer and preferably of monoisotopic constitution, is irradiated with γ rays and the resulting isomeric activity is determined. The cross section for this process contributes a lower limit to that for the (γ,γ') reaction because only part of the cascades following γ-ray absorption leads to the isomeric state of which the decay is detected. This fact, as well as the small number of suitable elements, constitutes a severe limitation on the technique. It has, on the other hand, the advantage of considerable experimental simplicity and great sensitivity, making it one of the few tools by which γ-ray absorption below particle emission threshold can be studied conveniently.

Cameron and Katz[3] were the first to employ this technique; they studied the inelastic scattering from gold through the reaction $Au^{197}(\gamma,\gamma')Au^{197m}$ (7.5 sec). Their results indicated that the cross section for this reaction has a single maximum located at the same energy (15 Mev) as the giant resonance peak of gold, as inferred from $Au^{197}(\gamma,n)Au^{196}$. This result appeared surprising in view of the observations in subsequent analogous experiments on $Rh^{103}(\gamma,\gamma')Rh^{103m}$ [4] and $In^{115}(\gamma,\gamma')In^{115m}$.[5] The cross sections for these processes were found to exhibit peaks at lower energies than for gold and far below the respective absorption peaks; though, since the target elements involved are lighter than gold, these absorption peaks lie at higher energies than the absorption peak of Au^{197}. Furthermore, simple

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* A report on this work was presented at the 1955 Mexico City meeting of the American Physical Society; see L. Meyer-Schützmeister and V. L. Telegdi, Phys. Rev. **100**, 961(A) (1955).

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