

DECAY OF $^{93}\text{Nb}^m$

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Abstract: The isomeric level of ^{93}Nb has been investigated by means of a high-resolution intrinsic germanium detector. A gamma ray of (30.7 ± 0.1) keV corresponding to the unconverted gamma-ray transition to the ground state has been observed. The K-conversion coefficient has been found to be $\alpha_K = (2.58 \pm 0.15) \cdot 10^{-4}$, which corresponds to an M4 transition. The ratios of emission rates of K x-ray components have been measured and found to be in agreement with a recent theory. This indicates the importance of exchange effects in the radiative decay of a K-vacancy state.

1. Introduction

The first excited state at approximately 30 keV in ^{93}Nb is an isomeric state with a half-life of 13.6 years¹⁾. The K/L and $K/(L + M)$ ratios for this state were previously measured by a proportional²⁾ and a scintillation³⁾ counter, respectively, while the $L/(M + N)$ and $\alpha_K/\alpha_{\text{total}}$ ratios were investigated using a semiconductor detector⁴⁾. These measurements indicate that the isomeric level decays to the ground state via an M4 transition ($1/2^- \rightarrow 9/2^+$). Furthermore, it was estimated that the transition probability for this decay is enhanced by a factor of 13.2 as compared with the Weisskopf single-particle transition rate⁴⁾. However, thus far no direct unconverted gamma ray to the ground state has been observed and no K-conversion coefficient, α_K , determined.

In this work, an unconverted gamma ray, corresponding to the direct transition from the first excited isomeric state to the ground state was observed and the K-conversion coefficient was determined. The ratios of K x-ray emission rates $K\beta'_1/K\alpha$, $K\beta'_2/K\alpha$ and $K\beta/K\alpha$ were also obtained. Experimental results were compared with existing theoretical predictions.

2. Apparatus

A calibrated $^{93}\text{Nb}^m$ source was supplied by Commissariat à l'Énergie Atomique, Bureau National de Métrologie. The source had an activity of $2.49 \cdot 10^6$ K x-rays/ $4\pi \cdot \text{min}$ with a quoted error of less than 5%. A General-Electric high-purity germanium photon spectrometer with an intrinsic germanium detector was used to detect photons. The detector was 0.619 cm in diameter and 0.4 cm thick; it had a Be window $2.54 \cdot 10^{-3}$ cm thick, placed in front of the crystal. The outputs from the preamplifier were fed through a linear amplifier into a 1024-channel analyzer. The system had a resolution of 340 eV for the 16.6-keV $K\alpha$ x-ray from the $^{93}\text{Nb}^m$ source.

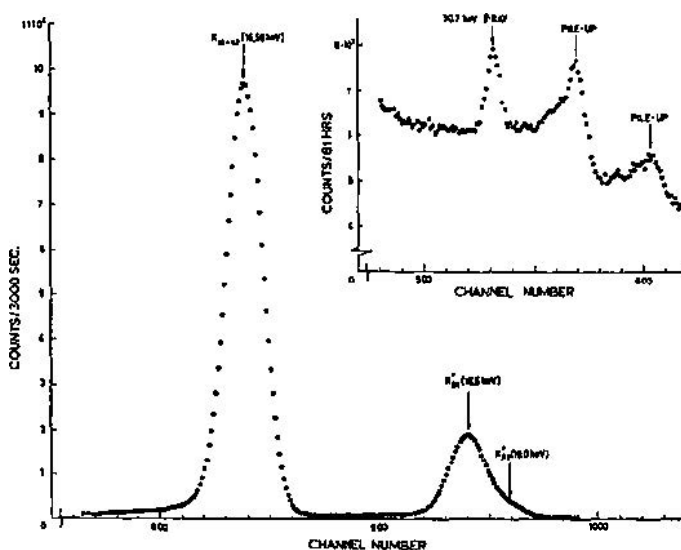


Fig. 1. Typical photon spectra of a radioactive $^{93}\text{Nb}^m$ source.

The energy calibration of the system and the efficiency curve of the spectrometer were determined using standard calibrated radioactive sources. The linearity of the system was found to be better than 0.1%. At the energies of interest, escape effects due to the small volume of the germanium crystal were not negligible and adequate corrections to the efficiency curve were, therefore, made. The overall uncertainties in the efficiency curve were less than 5%.

A NOVA 1220 minicomputer with a stripping programme written in the BASIC code was used to analyze photon spectra. The spectra were fitted by the χ^2 -method, assuming a Gaussian shape for photon peaks and a third- or a fourth-order power-series polynomial for the background.

3. Experimental results and analysis

Fig. 1 represents typical $^{93}\text{Nb}^m$ photon spectra. The gamma-ray spectrum, displayed in the insert, shows a peak at the energy $E_\gamma = (30.7 \pm 0.1)$ keV. This energy is in agreement with the transition energy of the first excited isomeric state in ^{93}Nb estimated from measurements of conversion electrons³⁾. Peaks at higher energies in the same spectrum were identified as pile-up events caused by intense K x-radiation.

The decay rate of the 30.7 keV transition was also measured. From the variation of gamma-ray intensity during a one-year period, an upper limit of $T_{1/2} \geq 5$ years for the half life was obtained. This is an additional piece of evidence that the observed gamma ray is due to the decay of the isomeric level in ^{93}Nb .

Table 1
Ratios of emission rates of K x-ray components.

	$K\beta_1/K\alpha$	$K\beta_2/K\alpha$	$K\beta/K\alpha$
Hansen et al. ⁶⁾			0.1886 ± 0.0038
Present work	0.163 ± 0.006	0.0251 ± 0.0011	0.190 ± 0.006
Scofield (1969) ⁹⁾	0.1556	0.0215	0.1772
Scofield (1974) ⁷⁾	0.169	0.0254	0.1949

Table 2
 K -conversion coefficients for the 30.7-keV transition in ^{93}Nb for five independent runs.

Run No	Time of measurement (in hours)	$\alpha_K \cdot 10^4$
1	62.4	2.70 ± 0.22
2	51.8	2.68 ± 0.21
3	61.2	2.54 ± 0.21
4	50.9	2.54 ± 0.21
5	50.6	2.45 ± 0.22
	Weighted average	2.58 ± 0.15

The K -conversion coefficient was measured by the x-ray peak to gamma peak method. Five independent runs were made, the total time of data collection being 277 hours. The K -conversion coefficient for each run was calculated by the expression

$$\alpha_K = \frac{N_{Kx}}{N_\gamma} \frac{\epsilon_\gamma t_\gamma}{\omega_K} \frac{1}{\epsilon_{K\alpha} t_{K\alpha} (1 + K\beta/K\alpha) + \epsilon_{K\beta} t_{K\beta} (1 + K\alpha/K\beta)} \quad (1)$$

Here N_{Kx} is the total number of $K\alpha$ and $K\beta$ x-rays detected per unit time, N_γ is the number of 30.7-keV photons per unit time, ε_γ , $\varepsilon_{K\alpha}$ and $\varepsilon_{K\beta}$ are the total photopeak efficiencies of the germanium detector for the corresponding gamma and K x-rays.

t_γ , $t_{K\alpha}$ and $t_{K\beta}$ are the transmission coefficients which take into account the absorption of gamma rays and K x-rays in the source. The transmission coefficients were measured using collimated gamma rays of different energies. For the energies of interest, the transmission coefficients differ only by approximately 2%. For $K\beta$ x-ray, $t_{K\beta} \approx 0.95$.

ω_K is the fluorescent yield. For ^{93}Nb , we used the best fitted value $\omega_K = 0.748 \pm 0.032$, given by Bambynek et al.⁵⁾

The ratio of emission rates $K\beta/K\alpha$ was determined experimentally. Although the energy separation between $K\beta'_1$ and $K\beta'_2$ was approximately 400 eV (see Fig. 1), we were able to determine intensities of the $K\beta'_1$ and $K\beta'_2$ peaks by using the computer stripping programme. The ratios of emission rates for the two $K\beta$ components were found by the expression

$$\frac{K\beta'_i}{K\alpha} = \frac{N_{K\beta'_i}}{N_{K\alpha}} \frac{\varepsilon_{K\alpha}}{\varepsilon_{K\beta'_i}} \frac{t_{K\alpha}}{t_{K\beta'_i}}, \quad i = 1, 2, \quad (2)$$

where $N_{K\beta'_i}$ is the number of counts in the $K\beta'_i$ x-ray peak, $\varepsilon_{K\beta'_i}$ is the efficiency and $t_{K\beta'_i}$ the transmission coefficient for the corresponding $K\beta$ x-ray component.

Experimental results for the ratios of emission rates and for K -conversion coefficients are given in Tables 1 and 2, respectively. The $K\beta/K\alpha$ ratio is given as a sum of ratios of the two $K\beta$ component emission rates, $(K\beta'_1 + K\beta'_2)/K\alpha$.

4. Discussion and conclusion

The measured value for the $K\beta/K\alpha$ ratio is in good agreement with the result of Hansen et al.⁶⁾ The experimental data obtained are in agreement with recent theoretical predictions of Scofield⁷⁾. In his paper, Scofield used separate Hartree-Fock solutions for the initial and final states of the atom and included exchange effects of the nonzero overlap of wave functions from different subshells.

A further test of the theory could be made by comparing the emission-rate ratios for different $K\beta$ x-ray components. As can be seen from Table 1, the experimental ratios $K\beta'_1/K\alpha$ and $K\beta'_2/K\alpha$ are also in very good agreement with the theory of Scofield⁷⁾. This indicates the importance of exchange effects in the radiative decay of a K -vacancy state.

Our experimental value for the K -conversion coefficient $\alpha_K = (2.58 \pm \pm 0.15) \cdot 10^{-4}$ can be compared with the theory of Hager and Seltzer⁸⁾. Using the tabulated values for the conversion coefficients for $Z = 41$ and the M4 transi-

tion, we interpolated at the energy of 30.7 keV and found $a_K = 2.67 \cdot 10^{-4}$. This is in good agreement with our experimental result. It may, therefore, be concluded that the transition from the isomeric to the ground state in ^{93}Nb is an M4 transition.

References

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RASPAD $^{93}\text{Nb}^m$

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Sadržaj

Prvo uzbuđeno stanje u jezgri ^{93}Nb na energiji približno 30 keV je izomerno stanje s poluvremenom raspada 13.6 godina¹⁾. Iako dosadašnja istraživanja²⁻⁴⁾ ukazuju da se to stanje raspada preko M4 prijelaza ($1/2^- \rightarrow 9/2^+$) do sada nije videna direktna nekonvertirana γ zraka na osnovno stanje, niti je određen koeficijent K -konverzije a_K .

Pomoću intrinzičkog germanijevog detektora visoke rezolucije opažena je γ zraka energije (30.7 ± 0.1) keV koja odgovara spomenutom prijelazu na osnovno stanje. Koeficijent K -konverzije a_K mjereno je metodom XPG. Određeni su koeficijenti transmisije kao i omjeri doprinosa K x-zraka iz čega je onda dobiven $a_K = (2.58 \pm 0.15) \cdot 10^{-4}$ što odgovara M4 prijelazu. Dobiveni omjeri doprinosa K x-zraka slažu se s teorijom Scofielda⁷⁾ što ukazuje na važnost efekata izmjene u radijativnom raspadu stanja s K šupljinom.