Study of anomalies in $K\beta/K\alpha$ ratios observed following K-electron capture

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$K\beta/K\alpha$ measurements for Ti, V, Cr, Fe, Cu, and Zn have been performed for cases of K vacancies created by K-electron capture and x rays. For nuclei with $Z < 28$, a marked difference in the $K\beta/K\alpha$ ratios obtained by the two modes has been found.

I. INTRODUCTION

It is generally accepted that on grounds of existing theories x-ray emission following K-electron capture is characteristic of a transition from an almost-stationary pure K state. Processes in which the K hole is created by weakly ionizing particles, such as photons and electrons, are assumed to yield $K\beta/K\alpha$ ratios which do not differ from those obtained following K-electron capture.

Hansen *et al.*[1] determined the $K\beta/K\alpha$ ratios for a large number of nuclei ranging from $Z=17$ to $Z=82$ by measuring the characteristic x rays following the decay by K-electron capture. The data displayed a marked departure from the body of $K\beta/K\alpha$ ratios measured via excitation by bremsstrahlung x rays or electron bombardment, in the region below $Z=28$. In the most recent evaluation of relative emission rates for K x rays,[2] no special treatment of radioactive data was made. To our knowledge, no explanation of this discrepancy was offered.

Besides the work of Hansen *et al.* there is a measurement[3] of the $K\beta/K\alpha$ ratio for Mn using a ^{55}Fe source. The same authors[3] also measured the $K\beta/K\alpha$ ratio for Mn using bremsstrahlung excitation. The ratios measured for these two modes were the same. The measurement of Schnopper,[4] who compared the spectral shape of x rays following the decay of ^{55}Fe and the electron bombardment of Mn, also indicates the identity of the deexcitation mechanism.

It seemed worthwhile to add experimental evidence of the $K\beta/K\alpha$ ratio in the $Z<28$ region, with special emphasis on the comparison of bremsstrahlung excitation and K-capture decay.

II. EXPERIMENT

Four elements, ^{48,49}V, ^{51}Cr, ^{54}Mn, and ^{57}Co, were studied in the same range where Hansen *et al.*[1] reported discrepancies with bremsstrahlung data. For completeness, the results obtained for two additional elements, ^{65}Zn and ^{67}Ga, are included. The ^{65}Zn, ^{67}Ga, and ^{48,49}V sources were prepared on the cyclotron of the "Rudjer Boškovič" Institute. Commercially produced ^{51}Cr, ^{54}Mn, and ^{57}Co sources were used.

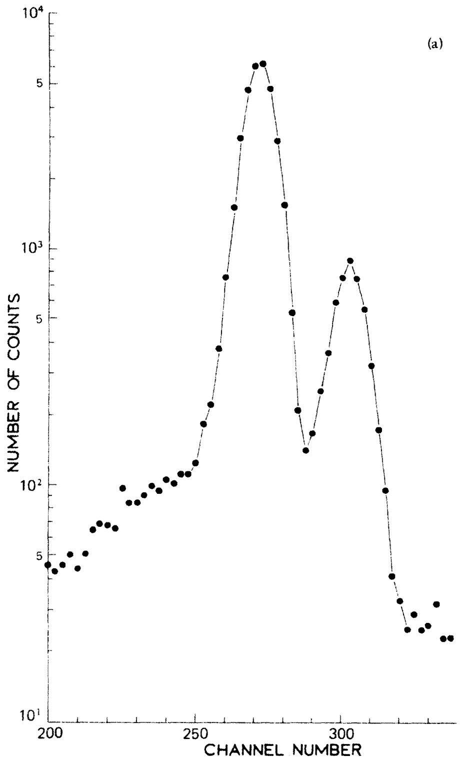
All sources (except ^{54}Mn) and targets were prepared from solutions which were allowed to dry up on thin plastic or metallic foils. The source and corresponding target were chosen so that, support, thickness, and dimensions be as similar as possible to minimize spurious effects. The ^{48,49}V source was prepared by dissolving the irradiated titanium in sulphuric acid. The source was mainly ^{48}V because it was used a few weeks after irradiation in the cyclotron. The typical thickness of the targets was 100 μg/cm^2. The ^{54}Mn source was an IAEA calibration source, in front of which a polythene foil 17.5 mg/cm^2 thick was placed.

X-ray spectra were measured using a Si(Li) detector of an area of 12 mm^2 with a Be window 25 μm thick. The resolution of the system was 180 eV at 6.4 keV. To minimize the possibility of errors in the absolute value of the $K\beta/K\alpha$ ratio, the same experimental setup was used to measure the $K\beta/K\alpha$ ratio in the case of excitation with bremsstrahlung x rays. X rays were produced in a 30-kV tube with a Mo anode. A fluorescer was used to clean the incoming x-ray spectrum. A Mo fluorescer was used in the case of Cu and Zn, while a Ge fluorescer was employed for the other elements. The thickness of the samples used for measurements was always chosen so that the corrections necessary be $< 0.1\%$.

III. RESULTS

The $K\beta/K\alpha$ ratios were extracted after the background subtraction. The background subtraction was performed using a five-parameter polynomial fitted on both sides of the peak. The analysis of the spectra was performed assuming identical shapes for the $K\alpha$ and $K\beta$ peaks, i.e., the distortion visible in the low-energy part of the $K\alpha$ peak was also reproduced in the $K\beta$ peak. Typical spectra are shown in Fig. 1.

The results obtained for the $K\alpha/K\beta$ ratio are shown in Table I. The errors quoted in the table represent the total uncertainty of the measure-



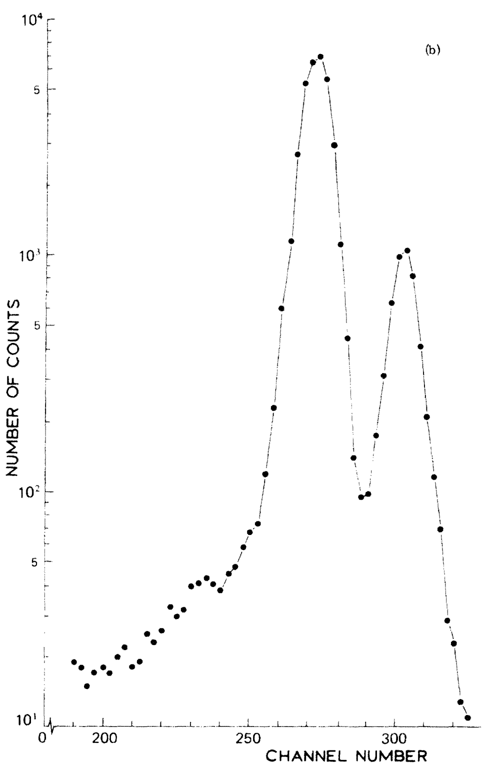


FIG. 1. Spectra of K x rays obtained by (a) K capture of $^{48,49}V$ and (b) bremsstrahlung excitation of Ti.

ments. The averaged and weighted data of Salem *et al.*[2] are shown for comparison. The $K\alpha/K\beta$ ratio obtained on the corresponding nuclei using x rays for excitation of vacancies in the K shell is also shown in Table I.

IV. ERRORS

The errors quoted in Table I took into account the following sources of errors: efficiency calibration, background subtraction, and counting statistics. It is, however, important to note that when comparing bremsstrahlung excitation with capture data, the efficiency calibration does not enter into account.

A. Efficiency calibration

The relative uncertainty in efficiency calibration for the $K\alpha$ and $K\beta$ lines involved was estimated to be always less than 1%.

B. Background subtraction

The background was typically (2–5)% of the $K\beta$ peak, thus introducing an error of approximately 0.3%.

C. Counting statistics

The statistical error in the number of counts in the $K\beta$ peak ranged from 0.3% to 0.9%.

V. CONCLUSION

It can be seen that the results obtained by x-ray excitation are in very good agreement with the evaluated values proposed by Salem *et al.*[2] On the other hand, it is obvious that significant differences exist between the $K\beta/K\alpha$ ratio for K-capture nuclei and that for x-ray excitation below $Z = 28$. Although the present measurement differs from Ref. 1 at $Z = 24$, the trend of the data corroborates the data of Ref. 1 and, in our opinion, establishes the necessity to treat the $K\beta/K\alpha$ ratio following K-electron capture in a way separate from electron or x ray excitation. This is not completely unexpected. In the capture process, the vacancy creation + nuclear-charge change do occur, contrary to other excitations in which the nuclear charge is not changed. One of the first consequences is the possibility of excitation of one or more of the noncaptured orbital electrons into unoccupied atomic bound and unbound states.[4] To reproduce the observed behavior of the K_β/K_α ratio, one should assume that the internal ionization of the M shell is more intense than that of the L shell. The calculations and measurements[5,6] indicate that the internal ionization of the

TABLE I. $K\beta/K\alpha$ ratios.

	$K\beta/K\alpha$			
Element	Compiled value Salem *et al.* (Ref. 2)	Present work x-ray excitation	Present work K-capture excitation	Hansen *et al.* (Ref. 1)
Ti	0.134	0.133 ± 0.002	0.123 ± 0.002	
V	0.1345	0.134 ± 0.002	0.121 ± 0.002	
Cr	0.135	0.134 ± 0.002	0.127 ± 0.002	0.1135 ± 0.0023
Fe	0.135	0.135 ± 0.002	0.129 ± 0.002	0.1283 ± 0.0025
Cu	0.1365	0.136 ± 0.002	0.137 ± 0.002	
Zn	0.138	0.137 ± 0.002	0.136 ± 0.002	

L shell following electron capture is a small effect. The probability for depleting L shells contributing to the $K\alpha$ line is always $< 10^{-3}$ per capture. According to the theory, the effect on the M shell should be even smaller; therefore, this cannot account for our observation. As mentioned in Sec. I, the data for Mn reported in Refs. 3 and 4 do not support the present results and those of Ref. 1. Unfortunately, we were not in a position to check that data point. To summarize, we have measured the $K\beta/K\alpha$ ratio following K-electron capture in the region where the M shell is filling up. Our results corroborate the earlier results of Hansen *et al.* that the $K\beta/K\alpha$ ratios for these nuclei are significantly different from those for K vacancies created by x rays.

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