Measurement of Sc and V K-shell ionization cross sections by slow electron impact

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Abstract Electron-induced Sc and V K-shell ionization cross sections, which are scarce, have been obtained from measurement of K_α X-ray emission cross sections at energies from near threshold to 25 keV. The influence of substrate of thin targets on ionization cross sections has been corrected using the bipartition model of electron transport.
Keywords Electron-induced K-shell ionization cross sections, Thin target with thick substrate, Electron transport

1 Introduction

It is accurate and precise measurements of atomic K-shell ionization cross sections by slow electron impact that not only have important significance for understanding the interaction between electrons and atoms, but also play an important role in such applications as X-ray microanalysis and the construction of heavy ion source providing highly charged ions[1]. In low energy region self-supporting uniform and thin targets are difficultly prepared. In order to overcome this difficulty thin targets with thick substrate are employed in our experiments. Since electrons reflected from the substrate should induce ionization of the target atoms, which will increase the number of counts of characteristic X-rays, correction should be made for this effect. The correction method needs to know reflection spectra of incident electrons from the substrate, which can be precisely calculated according to so-called bipartition model of electron transport[2,3]. The correction method has been successfully applied to analyze experimental data of Cr, Co, Cu, etc elements.[4,5]

This paper presents experimental results of Sc and V elements, which are measured for the first time at the energies from near threshold to 25 keV.[6]

2 Experiment

K-shell ionization cross sections have been deduced from K_α X-ray emission cross sections measured in impact energies between near threshold and 25 keV. Our experimental apparatus is similar to that given in Ref.[4]. A continuously adjustable power supply is used to accelerate electrons. The size of beam spot on the target is less than 2 mm in diameter and beam current is adjusted in accordance with X-ray counting rate. All charges of electron beam are collected by a deep Farady cup and are led to an ORTEC model 439 digital current integrator. A thin target, evaporated into thick aluminium backing, is placed at 10° with respect to the beam direction, and the characteristic X-rays emitted from the target atoms are detected by a Si(Li) detector positioned at 70° to the electron beam. The detector FWHM is 180 eV for Mn-K_α X-rays.

Since ionization cross sections are very sensitive to impact electron energy near the threshold, so accelerating voltage must be precisely determined. The high voltage of power supply is sampled by a precise resistor divider and the sampled voltage is measured by a FLUKE 8520A precision digital voltmeter. At the same time the incident energy of electron beam is determined at the endpoint of bremsstrahlung spectrum obtained by a datum acquisition system, which consists of an ORTEC 450 research amplifier and a multiple channel analyzer (ORTEC MCA 916) built in an IBM 386 personal computer and has been calibrated for energies. The relation between the energies of the endpoints of bremsstrahlung spectra and the sampled voltages is obtained by least-square fit. Throughout an experiment the energy of the beam can be monitored. With

Manuscript received date: 1996–06–01

this method the incident energy of electrons can be accurate within an uncertainty of less than 0.1 keV.

In order to deduce K-shell ionization cross sections from the K_α X-ray emission cross sections the detection efficiency of this system must be calibrated. For this purpose, standard radioactive sources (^{55}Fe, ^{57}Co, ^{241}Am and ^{137}Cs) are placed at the target position, X- and γ-rays from them are detected by the Si(Li) detector. The curve of detection efficiency of the system is shown in Fig.1. The uncertainty of calibrated efficiency is less than 0.05.

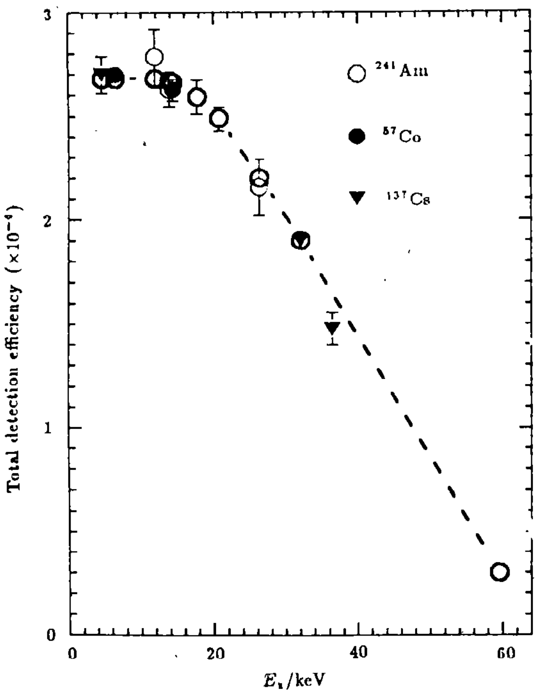

Fig.1 Total detection efficiency of X-rays as a function of X-ray energy

The targets employed in our experiments are evaporated into an aluminium backing by using vacuum coating technology in which their thickness is monitored and measured by a quartz oscillator. The uncertainty of target thickness should be less than 0.10. Their purities are better than 0.999 and their homogeneity is probed by recording the beam induced X-rays from the different points on them. The repeatabilities of data are found to be consistent within uncertainty of 0.15. The thickness range of targets is 5~10μg/cm^2, so the value of $\Delta E/E_e$ does not exceed 0.005, where E_e is the energy of incident electrons and ΔE is the energy loss through a target layer. The thickness of the backing is much larger than the penetrating depth of electrons with energy of 25 keV.

3 Results

The thin targets with a thick backing are used for measuring electron-induced ionization cross sections and correction should be made for influence of the backing on the data. The correction method used here is based on the bipartition model of electron transport[2,3] and has been described in detail in Ref.[4]. Here, the final formula for K-shell ionization cross section Q_K is given as follows:

$$Q_K = \left(\frac{4\pi}{\eta\Omega}\right)\cdot\frac{N_x(E)A}{N_e N_A (T/\cos\theta)\rho\omega_K}$$

$$\cdot\left(1+\frac{I(\beta)}{I(\alpha)}\right)-\cos\theta\int_{E_K}^{E}\phi_{ref}(E')Q_K(E')\mathrm{d}E' \quad (1)$$

where ω_K is the K-shell fluorescence yield, $N_x(E)$ the K_α X-ray counts, N_e the number of incident electrons, N_A and A Avogadro constant and atomic mass, respectively, ρ the target density, T the target thickness, $I(\alpha)$ and $I(\beta)$ refer to K_e and K_β X-ray intensities, respectively, θ the angle between the beam incidence direction and the normal of target plane. The total detection efficiency ($\eta\Omega/4\pi$) for K_α X-rays is taken from Fig.1. Electron energy spectra reflected from the backing ϕ_{ref} are precisely calculated by using the bipartition model of electron transport. After performing iteration in Eq.(1) the corrected K-shell ionization cross sections are obtained. The second term in Eq.(1) is used to correct contribution from the backing. In general, the corrected cross sections will decrease 0.10~0.25, compared to the uncorrected. The parameters of targets used here are given in Table 1. The present results are plotted in Figs.2,3 and also listed in Table 2. Errors mainly come from net X-ray peak counts (0.05), detection efficiency, fluorescence yield (0.06), target thickness (0.10) as well as inhomogeneity of the target (0.04). The total uncertainty added in quadrature of all errors is less than 0.15.

Table 1 Parameters for Sc and V elements

	Z	A	ω_K	E_K/keV	$I(\beta)/I(\alpha)$	$\rho T/\mu g \cdot cm^{-2}$
Sc	21	44.956	0.190	4.4895	0.131	5.0
V	23	50.940	0.250	5.4657	0.134	5.0

Table 2 Uncorrected and corrected K-shell ionization cross sections Q_K ($10^{-28}m^2$) for Sc and V elements in present experiment and the numbers in parantheses refer to total errors

	E_e/keV	Uncorrected	Corrected	E_e/keV	Uncorrected	Corrected
Sc	5.60	403(±43)	379(±40)	16.56	1118(±123)	913(±99)
	6.56	542(±55)	465(±49)	18.67	1110(±126)	896(±100)
	8.54	908(±97)	798(±85)	20.75	1086(±115)	868(±90)
	10.52	1060(±113)	902(±96)	22.84	1047(±125)	834(±99)
	12.47	1129(±121)	948(±101)	25.03	1036(±112)	814(±86)
	14.66	1131(±121)	938(±98)	–	–	–
V	6.51	178(±20)	170(±19)	12.45	838(±95)	748(±80)
	7.41	391(±42)	367(±40)	15.40	887(±101)	784(±82)
	8.45	549(±59)	501(±54)	17.95	973(±113)	812(±92)
	9.38	678(±75)	607(±67)	20.52	951(±113)	778(±90)
	10.40	764(±84)	670(±73)	22.36	987(±124)	788(±99)

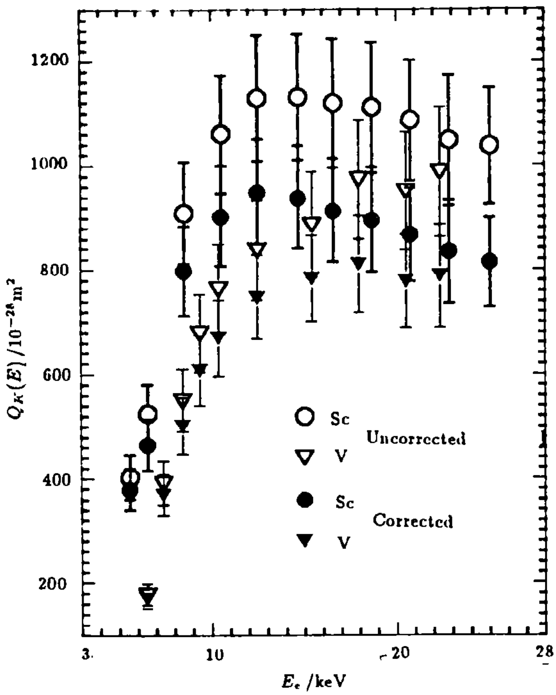

Fig.2 Sc and V K-shell ionization cross sections as a function of electron energy

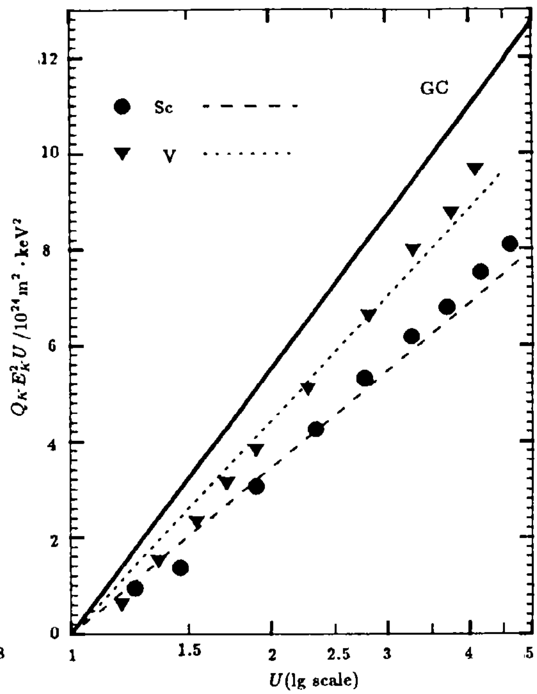

Fig.3 Sc and V K-shell ionization cross sections in the $Q_K E_K^2 U$ vs U representation. Empirical cross sections of Green and Cosslett (GC) are drawn by a solid line

In Fig.2, the present uncorrected and corrected data for Sc and V elements are drawn. Fig.3 presents our measured cross sections (i.e., corrected cross sections) transformed into scaled cross sections multiplied by scaled energy ($Q_K E_K^2 U$) as a function of lg(U) and in comparison with the results of semi-empirical formula of Green and Cosslett[7], that is presented as follows:

$$Q_K E_K^2 U = 7.92 \times 10^4 (\ln U), \quad (\mathrm{b} \cdot \mathrm{keV}^2) \quad (2)$$

where $U = E/E_K$.

In sum, for the first time we give the K shell ionization cross sections of Sc and V elements by electron impact at the energies from near threshold to 25 keV using thin targets with thick backing. The effect of thick backing on the measured cross sections has been corrected. It is again shown that our datum analysis method, based on the bipartition model of electron transport, works well. This will benefit measuring K shell ionization cross sections of more elements with few difficulties in preparing targets, especially in the lower energy region.

Acknowledgement

We are grateful to Mr. Xu Guo-Ji at CIAE for preparing targets used in the study.

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