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MEASUREMENT OF L-SHELL IONIZATION CROSS SECTIONS FOR NIOBIUM BY ELECTRON IMPACT*

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L-shell ionization cross sections of Nb by electron impact in the energy range from 3 to 40 keV have been determined with a Si(Li) X-ray detector. Influence of reflected electrons from backing on the measurement was corrected using an electron transport model. The experimental results are compared with theoretical calculations of Gryzinski and McGuire.

Keywords: L-shell ionization cross section, niobium, electron impact
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I. INTRODUCTION

During the past years there was a growing interest, experimentally as well as theoretically, in electron impact ionization cross sections. Lots of experimental and theoretical works have recently been devoted to this study.[1−11] Data of this type are required in many fields, e.g. the electron probe microanalysis, Auger electron spectroscopy, and electron-energy-loss spectroscopy. In addition, the diagnosis of fusion reactors (both inertial and magnetic) where considerable energy is lost in the ignition process due to X-ray production from highly stripped ions or inner-shell excitations. Unfortunately, such measured data, especially for L and M shells at lower energies, are quite scarce and in some cases there are no data at present. Values of this type are also important to find to what extent the existing theoretical models can elucidate the experimental data in the energy range from threshold to several tens of keV.

II. EXPERIMENTAL

The experimental arrangement is shown in Fig.1. An electron beam with energies from 3 to 40 keV was produced by an electron gun and a 60 kV dc power supply was used to accelerate the electrons. The high voltage power supply could be stabilized to the extent of one thousandth of the voltage applied. Focused monoenergy electron beam hit the target through two graphite apertures on the 0° beam line. The spot on the target was less than 3 mm in diameter. The horizontal dipstick of Si(Li) detector was inside the target chamber and about 10 cm from the center of the target, which was placed at 45° inclined to the direction of incoming beam . The detector had a 12mm^2 active area, a 3.5mm active depth, and an energy resolution of 180eV (full width at half maximum) at 5.9keV for Mn$K\alpha$ X-rays. A deep graphite Faraday cup was employed to collect the charges on and through the target. The Faraday cup was coupled to an ORTEC model 439 digital current integrator. During experiment the vacuum was kept less than 3×10^{-3}Pa in the chamber and the intensity of beam was adjusted to about 1 nA to reduce pulse pileup effect. Generally, the target should be thin enough to minimize (i) the degradation of the beam energy and intensity, (ii) the bremsstrahlung production, and (iii) the self absorption of X-rays. In the present study a Nb target of 28.8 μg/cm^2 was used, which was sputtered on a carbon substrate of 63μg/cm^2. The thickness of Nb tar-

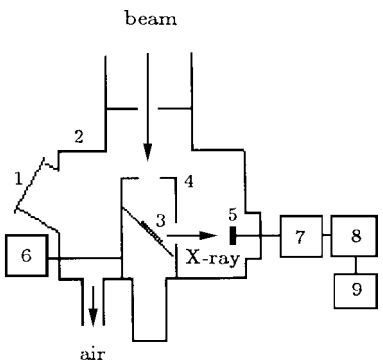


Fig.1. Experimental arrangement. 1: view window; 2: chamber; 3: target; 4: Faraday cup; 5: Si(Li) detector; 6: charge integrator; 7: preamplifier; 8: main amplifier; 9: MCA.

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get was determined by weighing, using a balance with a precision of 10^{-6}g. The efficiency calibration of the Si(Li) detector was performed by a set of standard sources.

Ⅲ. RESULTS AND DISCUSSION

Because the Si(Li) detector cannot resolve the Lα-X-rays, Lβ-X-rays and Lγ-X-rays from the resulting peak of measured energy spectra of Nb, so only the total L-shell production cross section $\sigma_{\rm LX}$ can be given from the L X-ray counts $N_{\rm LX}$ by following formula

$$\sigma_{\rm LX} = \frac{4\pi N_{\rm LX}\cos\theta}{N_{\rm e} dn\varepsilon\Omega}, \qquad (1)$$

where θ is the angle between the incoming beam and the normal of the target surface, $N_{\rm e}$ the number of electrons hitting the target of thickness d (cm) and density n (atom/cm^3), ε the efficiency of detector, Ω the solid angle subtended by the beam spot to the detector's effective area. The mean ionization cross section can be written as

$$\overline{\sigma}_{\rm L} = \frac{\sigma_{\rm LX}}{\overline{\omega}_{\rm L}},$$

where $\overline{\omega}_{\rm L}$ is the mean fluorescence yield of L-shell.

The main sources of the total production cross section uncertainties come from the target thickness inhomogeneity (<5%), the detector efficiency (~4%), the beam integration (<3%) and the counting statistical errors (2%–6%). Not taking into account the errors of constants used in the cross section calculation, the overall uncertainty of the cross section was estimated to be less than 10%. The mean fluorescence yields and ionization energies of L-subshell used in evaluation procedure of the present study are given in Table 1.

Table 1. Mean fluorescence $(\overline{\omega}_{\rm L})^{\rm a)}$, ionization energy $(I_i)^{\rm a)}$ (in keV) for Nb.

$\overline{\omega}_{\rm L}$	I_1	I_2	I_3
0.026	2.695	2.462	2.368

a): taking from Ref.[15].

A typical X-ray spectrum for Nb is shown in Fig.2, and the total L-shell mean ionization cross sections $\overline{\sigma}_{\rm L}$ as functions of incident electron energy are plotted in Fig.3.

Because the preparation of a thin self-supporting target is difficult, a 63μg/cm^2 carbon film was used as backing in the present experiment. But the electrons reflected from the backing film, when inversely passing through the niobium target, may ionize niobium atoms once again, resulting in a systematic overestimation of the measured cross sections. We have calculated the fraction of L-shell ionization events caused by the electrons reflected from the carbon backing and the resulting L-shell cross section can be written as

$$\sigma_{\rm LX} = \frac{4\pi N_{\rm LX}\cos\theta}{N_{\rm e} dn\varepsilon\Omega} - \cos\theta\int_0^E \Phi_{\rm ref}(E')\sigma_{\rm LX}(E'){\rm d}E', \qquad (2)$$

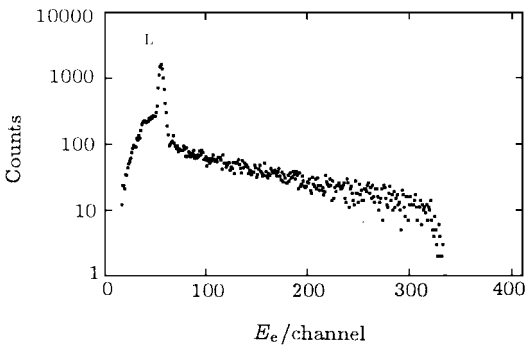


Fig.2. Typical X-ray spectrum for Nb at 11 keV of electron energy.

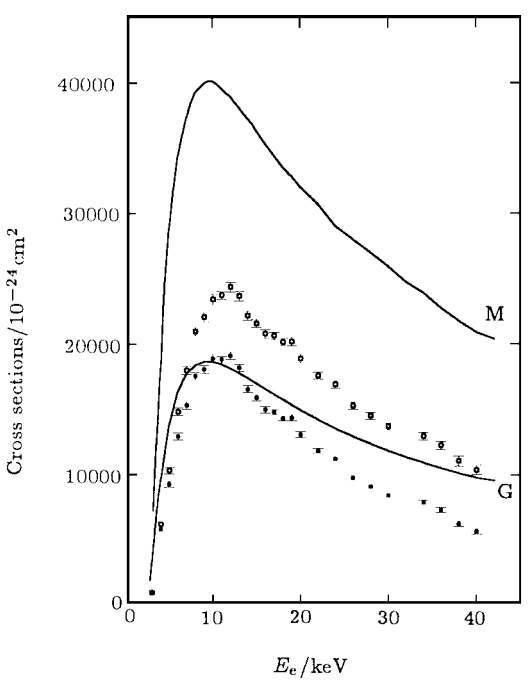


Fig.3. L-shell ionization cross sections for Nb as functions of electron energy: open circles, uncorrected data; solid circles, corrected data. M denotes the results of McGuire;[14] G is the results of Gryzinski.[13]

where the second term is the fraction of L-shell ionization events caused by the electrons reflected from the carbon backing and $\Phi_{\rm ref}(E')$ is the energy spectrum of the electrons reflected from the backing surface, which

can be acquired by using a so-called bipartition model for electron transport.[12] The symbol $\sigma_{LX}(E')$ is the ionization cross sections induced by the electrons with energy E'. Equation (2) can be solved by iteration(see Ref.[11]).The corrected values of the measured cross section and their errors are also presented in Fig.3 and Table 2.

Table 2. Uncorrected and corrected L-shell cross sections for Nb by electron impact.

Electron energy	Cross section/10^{-24}cm^2			
E_e/keV	Uncorrected	Error	Corrected	Error
3	943	48	906	46
4	6182	161	5818	152
5	10307	256	9252	229
6	14819	301	12938	263
7	17982	320	15304	272
8	20973	319	17553	267
9	22088	347	18061	284
10	23436	384	18899	310
11	23753	302	18813	239
12	24393	361	19118	283
13	23690	363	18178	278
14	22194	351	16541	261
15	21617	316	15871	232
16	20785	333	14989	240
17	20629	266	14800	191
18	20177	266	14336	189
19	20208	339	14362	241
20	18897	319	13077	221
22	17592	282	11842	190
24	16901	280	11244	186
26	15296	281	9756	180
28	14513	274	9098	172
30	13717	272	8430	167
34	12948	307	7881	187
36	12259	329	7315	196
38	11048	372	6230	210
40	10353	380	5658	208

In Fig.3 the measured cross section values for L lines from the present measurements are compared with two different calculations: the so-called BEA(binary encounter approximation) theory of Gryzinski[13] and the nonclassical scaling law of McGuire.[14] From Fig.3 we notice that the present experimental values are situated systematically under the results of McGuire and close to the calculated results of Gryzinski. By comparison the present results rather agree with Gryzinski's calculated values.

In conclusion, the correction of the influence of backing in the measurements for inner-shell ionization cross sections by using the energy spectra of reflected electrons will be beneficial to obtaining reliable experimental results from the measurements using thin target with a thick backing, considerably reducing the difficulties in preparation of thin self-supporting target.

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