MEASUREMENTS OF TOTAL CROSS SECTIONS FOR *K*-SHELL IONIZATION BY ELECTRON BOMBARDMENT

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ABSTRACT

Cross sections for *K*-shell ionization have been measured at electron energies of 0.1–0.40 MeV for Cu and Sn, and of 0.30MeV for Ag. The present results have been compared with theoretical calculations and previously reported experimental values.
Keywords *K*-shell, Ionization cross section, Electron

1 INTRODUCTION

A great deal of experimental and theoretical work has been devoted in recent years to the study of the ionization cross sections of atoms or ions by electron impact[1−3]. The importance of an accurate evaluation of these cross sections is evidenced by the wide variety of physical phenomena, the interpretations of which demand a knowledge of reaction rates for ionization by electron impact. Examples of such phenomena arise in the field of plasma physics, in study of stellar atomospheres and the solar corona, in studies of gas discharges and of the passage of shock waves through gases, and in astrophysics.

The determination of the atomic inner shell ionization cross section for electron bombardment is of basic importance in the attempt to understand better the inelastic electron-atom interactions. The available data on this process are, however, rather limited and so more data are needed. The present measurements are carried out to determine the *K*-shell ionization cross sections for Cu, Ag and Sn at electron kinetic energies from 100 to 400 keV.

2 EXPERIMENTAL METHOD

In this work the *K*-shell ionization cross sections have been measured at electron energies of 0.10, 0.15, 0.20, 0.25, 0.30, 0.35 and 0.40 MeV for Sn; 0.10, 0.15, 0.20, 0.30 and 0.40 MeV for Cu and 0.30 MeV for Ag. A schematic diagram of the apparatus used is shown in Fig.1. The electron from a 600 kV Cockcraft-Walton accelerator were incident on self-supporting targets of Cu, Ag and Sn. The self-supporting Cu, Ag and Sn targets were prepared by vacuum evaporation and their thickness were measured by a spectrophotometer. The targets were placed inside a cylindrical scattering chamber at an angle 45° with respect to the incident electron beam. The measurements of the characteristic X-rays following *K*-shell ionization were performed with a Si(Li) detector of 28 mm^2 active area and 5.27 mm active depth having 175 eV resolution at 5.9 keV.

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In order to suppress the intense L X-rays of the target elements, the detector was kept outside the vacuum chamber. A 13μm thick Mylar window is used to isolate the Si(Li) detector from vacuum chamber. The Si(Li) detector was positioned at 90 degrees to the beam direction and approximately 6 cm from the center of the target. The calibrated radioactive source ^{241}Am was used to determine the detection efficiency of the Si(Li) detector. The diameter of the ^{241}Am deposit is approximately the same size as that of the electron beam spot on the targets.

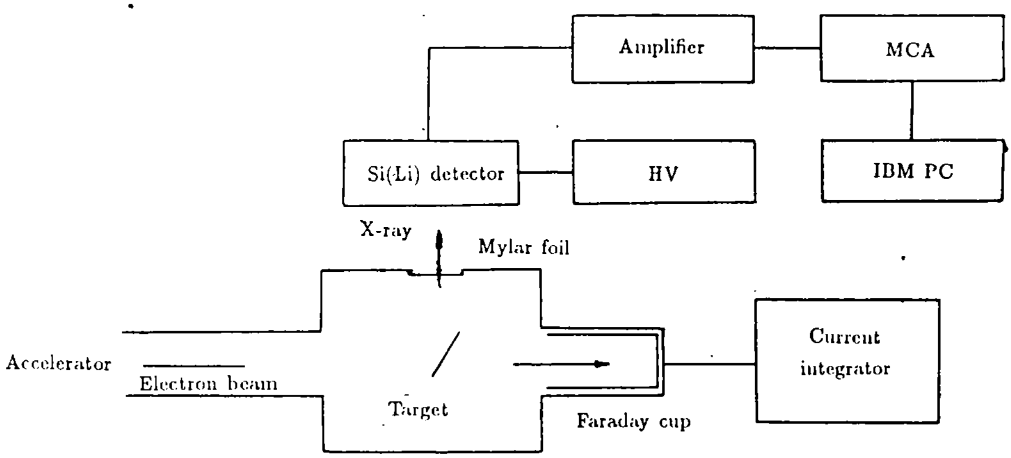

Fig.1 Block diagram of equipment

The experimental cross section for the ionization of the atomic K-shell electrons is determined from the following equation,

$$\sigma = 4\pi N_k/(Nt\Delta\Omega\epsilon\omega_k) \quad (1)$$

where N_K is the number of characteristic X-rays, t is determined from the effective target thickness and is equal to the number of target atoms per cm^2 normal to the beam direction. The targets were sufficiently thin so that corrections for the self-absorption in the targets were negligible, ε is the efficiency of the Si(Li) detector for the detection of the K X-rays emitted from the target, $\Delta\Omega$ is the solid angle substended by the collimator opening to the Si(Li) detector, N is equal to the number of electrons incident on the target and is determined from the electron charge collected by a Faraday cup and measured with a current integrator. Beam currents of up to 100 nA were employed for the X-rays measurements while care was taken to avoid any possibility of spectral distortion due to pulse pile-up effects, ω_k the probability of a K X-ray emission when an electron is removed from the K-shell (K-shell fluorescence yield). The fluorescence yields used were taken from the compilation by Krause[4]. ω_k=0.440 for Cu, ω_k=0.831 for Ag and ω_k=0.862 for Sn. The equation (1) requires isotropic emission for the K X-rays. No corrections were made for angular dependence of the X-ray yields as the K X-rays emission has been found to be isotropic.

In this work the ionization cross section is expressed in terms of the theoretical bremsstrahlung cross section according to the following relation,

$$\sigma = \frac{4\pi N_k}{N_b \omega_k} \int_{k_1}^{k_2} \frac{d^2\sigma}{d\Omega dk} \cdot dk \tag{2}$$

where N_b is the number of bremsstrahlung photons detected in the region k_1 to k_2 and $d^2\sigma/d\Omega dk$ is the theoretical bremsstrahlung cross section as tabulated by Kissel et al[5]. In this form both N_k and N_b depend in the same way on t, N and $\Delta\Omega$. Therefore, the ratio of the two is independent of these factors.

3 RESULTS AND DISCUSSION

A typical spectrum produced by electrons bombardment on Sn is shown in Fig.2.

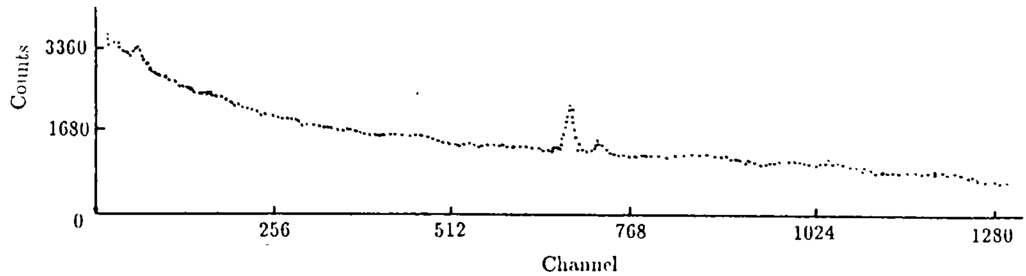

Fig.2 Typical spectrum of 0.3 MeV electron impact on tin atoms

The characteristic X-ray peaks are seen superimposed on the bremsstrahlung continuum. The present experimental cross sections for the atomic *K*-shell ionization of Cu Ag and Sn are shown in Figs.3, 4 and 5, respectively. In these figures the theoretical calculations of Arthurs and Moiseiwitsch[6] and Kolbenstvedt[7] and the previous measurements of Rester[8] and Davis[9] are also shown for comparison.

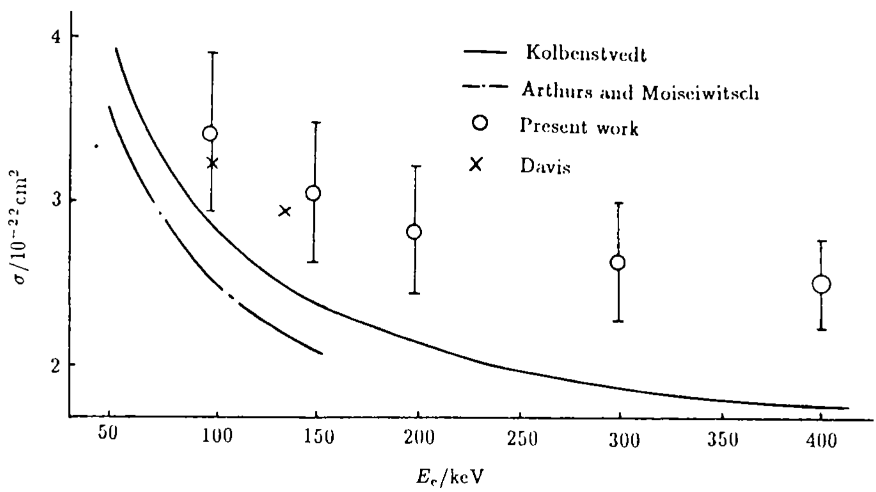

Fig.3 *K*-shell ionization cross section σ for copper as a function of electron kinetic energy E_e

In the calculation of Arthurs and Moiseiwitsch[6] the initial and final states of the projectile electrons are represented with relativistic free-particle wave function. For the atomic electron the initial and final states are represented with a nonrelativistic hydrogenic wave function and a nonrelativistic Coulomb wave function, respectively. They have calculated values for a parameter S from which the K-ionization cross section σ can

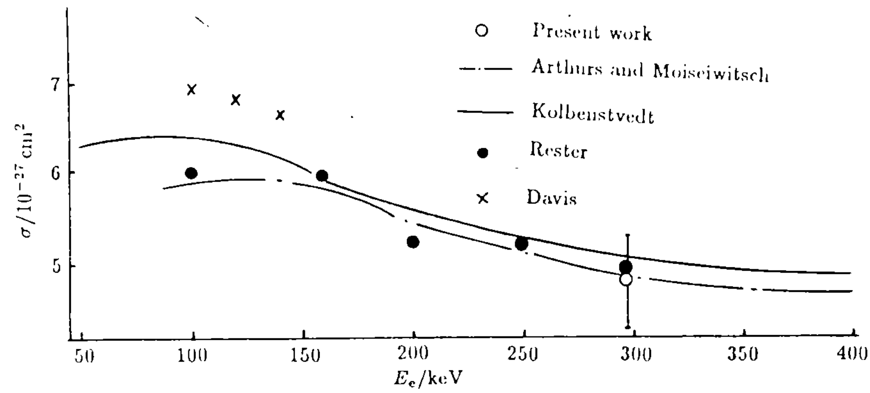

Fig.4 K-shell ionization cross section σ for silver as a function of electron kinetic energy E_e

be obtained for electron kinetic energies T extending from 2.5 to 20 times the K-shell binding energy I_k. The parameter S is defined as

$$S = [(137Z_e)^2(E_1^2 - 1)/(\pi a_0 E_1)]\sigma \quad (3)$$

where Z_e is the effective nuclear charge for the K shell and is equal to $(Z$-$0.3)$ where Z is the atomic number; E_1 is the total electron energy in mc^2 units and a_o is the hydrogen Bohr radius equal to 0.53×10^{-8}cm[10]. The values of S from which cross sections may readily be calculated are displayed as a function of T/I_k in Refs.[6, 10].

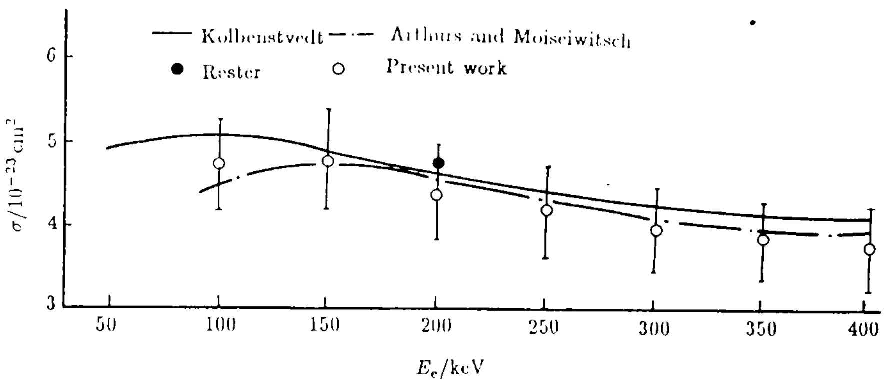

Fig.5 K-shell ionization cross section, σ, for tin as a function of electron kinetic energy, Ee, in keV

In the semi-emperical calculation of Kolbenstvedt[7] the total *K*-ionization cross section is simply taken as the sum of the contributions from large and small impact parameters.

$$\sigma = \sigma(b > a) + \sigma(b < a) \tag{4}$$

For practical purposes he writes the cross section in the form,

$$\sigma(b > a) = \frac{0.275}{I}\frac{(E+1)^2}{E(E+2)}[\ln\frac{1.19E(E+2)}{I} - \frac{E(E+2)}{(E+1)^2}] \tag{5}$$

$$\sigma(b < a) = \frac{0.99}{I}\frac{(E+1)^2}{E(E+2)}[1 - \frac{1}{E}(1 - \frac{E^2}{2(E+1)^2} + \frac{2E+1}{(E+1)^2}\ln\frac{E}{I})] \tag{6}$$

where E is the kinetic energy of the incident electron and I is the ionization energy, both in units of the electron rest energy, a is the *K*-shell radius and b is the impact parameters.

The errors on each cross section comprise statistical error and uncertainty in continuum background subtraction. All statistical errors are kept below 1% and therefore contribute a little to the total uncertainty. The predominant error in the experiment is an estimated uncertainty of 15% in the absolute scale of the theoretical bremsstrahlung cross section used in the normalization. The present results are in reasonable agreement with the previous experimental results of Rester[8] and Davis[9].

The Cu results lie systematically higher than either the semi-relativistic quantum theory of Arthurs and Moiseiwitsch[6] or semi-emperical calculation of Kolbenstvedt[7].

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