Measurements Of High-Energy-PIXE Cross Sections With 68 MeV Protons For Various Thin Target Elements

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ABSTRACT

In this paper we present measurements on K shell ionization cross sections for various elements ranging from Z=22 to Z=79 at a proton energy of 68 MeV.

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1. INTRODUCTION

The use of high energy protons (68 MeV) for PIXE analysis implies several advantages: High-energy protons have a large range and the K-shell ionization cross section is large enough to detect heavy elements by Kα- and Kβ-X-ray lines. Owing to the high energies of these K-lines, they will be less absorbed in overlying material allowing to analyze up to 1 cm.

For quantitative analysis, precise values of cross sections at high energies are highly desirable. However, in this energy region, experimental data for cross sections are scarce [1] and any quantitative analysis has to rely on theoretical calculations.

In this work, cross sections for K-shell ionization of various elements by 68 MeV protons are presented.

2. EXPERIMENT

The measurements were performed at the high-energy PIXE set-up [2] at the Ionenstrahllabor (ISL) of the Hahn-Meitner-Institut. The X-rays were detected by a high-purity Ge detector mounted at 135° relative to the proton beam direction. The detector has a resolution of 180 eV at 5.9 keV. Figure 1 shows the recorded spectra of copper and holmium.

The experimental parameters were: proton energy 68 MeV, beam current about 4 pA, irradiation time 15-30 minutes, depending on the sample, until sufficient statistics in the interesting peaks was obtained. The number of incident protons was measured by an ionization chamber, which was calibrated using a Markus chamber[3].

Thin layers of six elements (Ti, Cu, Mo, Sb, Ho, Au) were evaporated with a thickness of 0.1-0.5 µm onto 380 µm thick silicon substrates. The use of thin targets avoids X-ray absorption in the target. Only absorption in air between the target and the detector has to be taken into account. Furthermore, the energy loss of the protons in the target was negligible (less than 1 keV). Silicon substrates were chosen because they are robust, thin, and with PIXE in air, do not produce distinct lines in the spectra. Moreover, the smooth surface enables a better verification of the target areal density by means of ERDA (Elastic Recoil Detection Analysis). These measurements were performed using a beam of 350 MeV Au ions at the ISL with the Berlin TOF ERDA set-up [4] with an accuracy of about 10%, due to the uncertainties of the stopping power and densities used in the evaluation.
FIGURE 1. X-ray spectrum from a 112 nm thick target of Cu (left side), irradiated with 68 MeV protons for about 900 s, and 436 nm Ho (right side) irradiated for 1900 s. The spectra are compared with the spectrum from the pure silicon substrate.

3. CROSS SECTIONS

The ionization cross section is given by

$$\sigma_Z(E) = \frac{A}{N_p M(Z) \omega b \varepsilon \mu N_{AV}}$$  \hspace{1cm} \hspace{1cm} (1)

where $Y(Z)$ is the measured X-ray yield of element $Z$, $A$ the atomic mass (g/mol) of the element $Z$, $N_p$ the number of incident protons, $\omega$ the fluorescence yield from [5,6,7], $b$ the fraction of X-rays in this line [8], $\varepsilon$ the absolute detection efficiency, $\mu$ the corresponding absorption coefficient, $N_{AV}$ Avogadro number (atoms/mol), $M(Z)$ the target areal density (g/cm$^2$), and $E$ the proton energy.

The peak areas of the lines were determined by fitting the spectra with GUPIX [9,10].

Figure 2 summarizes the obtained ionisation cross sections in comparison with theoretical values of ECPSSR based GUCSA calculations [11,12] from the GUPIX software package and experimental values from Pineda and Peisach at 66 MeV [1].

FIGURE 2. Ionization cross sections at 68 MeV. Shown are the data from this work (squares), GUCSA (solid line), and from Pineda and Peisach obtained at 66 MeV protons (triangles).
4. CONCLUSIONS

All experimental values are at least 20% smaller than the theoretical calculations obtained in GUCSA. The differences in the ionization cross sections for protons with 68 MeV and 66 MeV are only about 1% for high Z materials, hence, the cross sections obtained in this work are also smaller than the ones from previous measurements [1]. The cross sections of nuclear reactions leading to internal conversion are so small compared to the ionization cross sections, that they are negligible. The experimental set-up will be thoroughly checked for possible systematic errors. In addition, measurements at lower proton energies are planned.

REFERENCES

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