Characteristic X-ray Production Cross Sections Using High Energy Ions

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The nuclear microprobe SNAKE (Supraleitendes Nanoskop für Angewandte Kernphysikalische Experimente) at the Munich tandem accelerator [1] offers the possibility of particle induced X-ray emission (PIXE) using high energetic ions. Although there are many groups working with 1-3MeV protons, there are only few one using higher proton energies [2] or even heavier ions. As a result, data for quantitative analysis using high energetic ions are scarce. Therefore, X-ray production cross sections induced by 16MeV protons and 70MeV carbon ions are measured at the SNAKE setup.

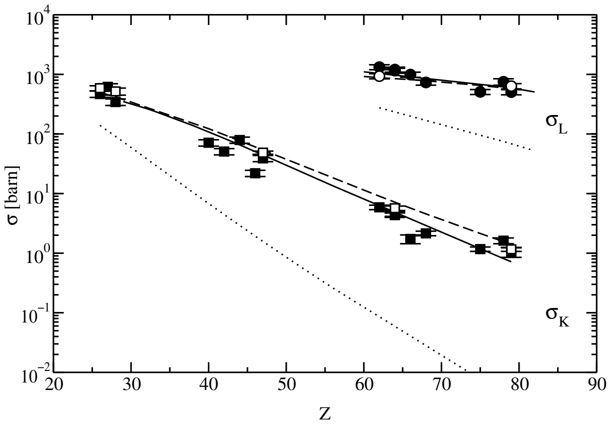

Fig. 1: X-ray production cross sections σ_K, σ_L using 16MeV protons for several target elements.

Figure 1 shows the measured cross sections σ_K and σ_L of 16MeV protons for several targets (filled symbols). In addition, experimental data found in literature [3,4] are depicted (open symbols) which are in good agreement with our measurement. Furthermore, cross sections are shown calculated from a semi-empirical description (solid line) [5] and the ECPSSR theory (dashed line) [6] using a computer code of K. Sera [7] the fluorescence and Coster-Kronig yields tabulated in [8]. The calculations are in reasonable agreement, although the experimental cross sections are in general lower and contain some fine fluctuations. The difference may be due to errors of the fluorescence and Coster-Kronig yields [9] and because ECPSSR theories do not describe subshell ionisation cross sections properly in any case [10]. The calculated cross sections for 3MeV protons (dotted line) are much lower than for 16MeV protons.

In figure 2 measured cross sections σ_K and σ_L of 70MeV carbon ions are shown for various target elements (filled symbols) [11]. Compared to 3MeV protons (dotted lines) X-ray production cross sections using 70MeV carbon ions are much larger. Semi-empirical (solid line) and ECPSSR (dashed line) cross sections are presented which are quadratically scaled with the carbon ions charge from protons of same velocity. The calculated cross sections over-estimate the data more than one order of magnitude for heavy elements. Only for light elements theory and experiment are in reasonable agreement. The scaled semi-empirical description is closer to the measured values but the deviations are still large. As the theoretical description is based on perturbation theory it may fail for heavy ions.

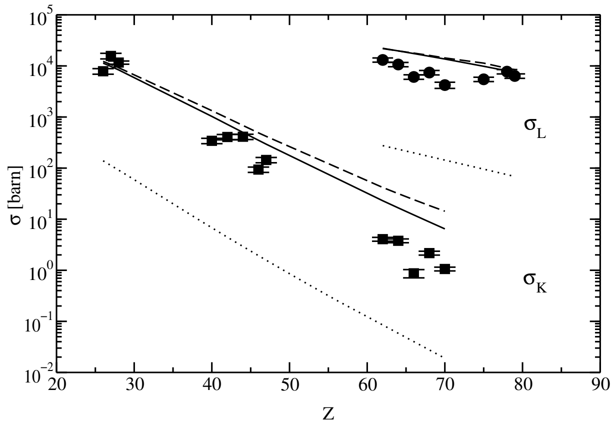

Fig. 2: X-ray production cross sections σ_K, σ_L using 70MeV carbon ions for several target elements.

In addition to the characteristic X-ray emission cross sections continuous X-ray emission cross sections are measured [11] which mainly result from secondary electron, quasi-free electron and atomic bremsstrahlung. The data show that the sensitivity in PIXE analysis, which is correlated to the signal to background ratio is within the same order of magnitude as for the commonly used 1-3MeV protons. Especially, the usage of the high energy protons, e.g. 16MeV, show several advantages when using them for PIXE at a nuclear microprobe. The enhanced X-ray production cross sections result in reduced ion currents and therefore in smaller beam spot sizes. In addition, in conjunction with the smaller stopping power of the higher energy protons, irradiation damage is reduced during PIXE analysis. As another advantage, the lateral spread decreases with ion energy [12] and therefore the lateral resolution in microscopic PIXE is improved. Since the cross section of the gold K-line is about one barn for 16MeV protons it is even possible to efficiently identify heavy elements not only by their L-lines but also by their K-lines. Hence, the analysing depth can be increased for heavy elements using high proton energies since the absorption of the K-lines is smaller than for L-lines and the range of the more energetic protons in matter is enlarged. At SNAKE it will be possible to apply these advantages in micro PIXE the first time.

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