X-ray emission in interaction of highly charged xenon ions with Be foil

Ł Jabłoński[1], D Banaś[1], J Braziewicz[1], J Czub[1], P Jagodziński[2], A Kubala-Kukuś[1], D Sobota[1], I Stabrawa[1], M Pajek[1]

[1] Institute of Physics, Jan Kochanowski University, 25-406 Kielce, Poland
[2] Department of Physics, University of Technology, 25-314 Kielce, Poland

E-mail: ljablonski@ujk.edu.pl

Abstract. In this work we report on the measurements of X-rays emitted in interaction of ~100 keV Xe^{35+} ions with metallic Be foil. Measured X-ray spectrum was interpreted as a series of satellite and hypersatellite nf-3d transitions with n≥4. The observed X-ray transitions from very high Rydberg states indicate the formation of so-called "hollow atoms" in the process of neutralization of highly charged ions on the metallic surface.

1. Introduction

The interaction of highly charged ions (HCI) with surfaces is dominated by a high coulombic potential energy of the projectile, as compared to its kinetic energy [1]. This conditions provide unique opportunity for formation the so-called "hollow atoms"[2] in the process of neutralization of HCI at surfaces in which, first, the electrons are captured into high Rydberg states while inner shells remain empty. Such highly excited exotic „hollow atoms" quickly deexcite in a cascade of Auger and radiative transitions. Consequently, the emitted Auger electrons and X-rays carry information about the structure and relaxation processes for these exotic, highly excited states.

We report here the results of experiment in which the "hollow atoms" are created in interaction of highly charged xenon ions with the metallic surface. The measured spectrum of emitted X-rays is interpreted using available atomic structure calculations for dominating dipole-allowed transitions and the predictions of the so-called Classical Over-barrier Model describing the neutralization of slow HCI colliding with a surface.

2. Experiments

In this experiment the X-rays emitted in interaction of ~100 keV Xe^{35+} ions with metallic Be foil were measured. The highly charged xenon ions were produced in the EBIT trap of the EBIS-A facility [3-5] by successive electron impact ionization of xenon atoms. The electron beam energy and current were 8.2 keV and 80 μA, respectively. The highly charged xenon ions created in the EBIT were extracted from the trap in a pulse mode and after selecting Xe^{35+} charge state in the analyzing dipole magnet the ion beam was focused on a Be foil mounted on a manipulator. The X-rays were measured with a 25 μm thick silicon drift detector (XFlash 5010, Bruker) having energy resolution of about

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127 eV for Mn Kα line. In these experiments the whole system was kept at UHV conditions, at 10^{-10} mbar level.

3. Results and discussion

The measured spectrum of X-rays emitted in interaction of slow Xe^{35+} ions with Be foil is shown in figure 1. This spectrum can be interpreted as a result of electronic dipole-allowed radiative transitions from high Rydberg states, populated in a process of neutralization of HCI at the surface, into n=3 vacancy states in Xe^{35+} leading to emission of M-X-rays.

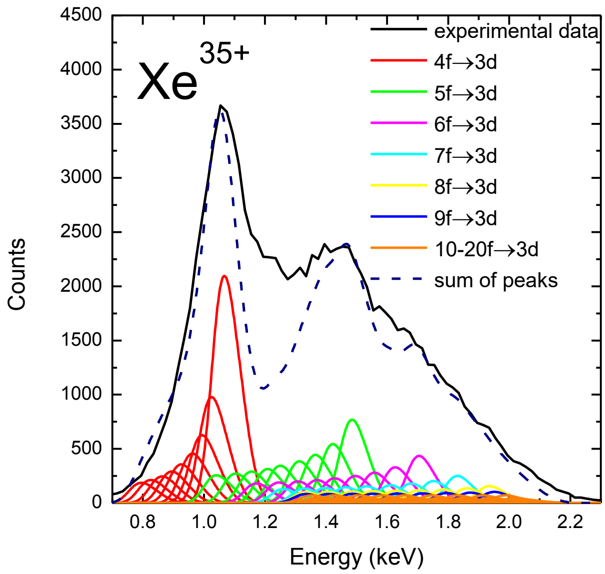

Figure 1. Measured spectrum of X-rays emitted in interaction of ~3 keV×q Xe^{35+} ions with Be foil compared with theoretical predictions.

Xe^{35+} ions have vacancies in the 3d subshell (see figure 2). Consequently, the X-ray spectrum is expected to be dominated by nf-3d transitions assuming the electric dipole selection rules and hydrogenic oscillator strength values. For any of these transitions we expect nine hypersatellite lines corresponding to nine 3d vacancies which can be filled by electrons. The energies of the transitions were calculated using the electron binding energies taken from [6]. The relative intensities of hypersatellits were assumed to be scaled as $1/(M-1)^{\alpha}$, were M is a number of electrons in the 3d subshell in the final state and α is an adjustable parameter that describes the relative intensities of hypersatellites taking into account its possible dependence on the principal quantum number of high Rydberg stated considered, or more precisely a change of amount of electrons in a higher state caused by the capture of electrons from higher shells and Auger processes. In case of analysed spectrum, the estimated value of α varies from 1.1 (transitions from n=4 shell) to 0 (transitions from the n≥10 shells). The FWHM width of hypersatellite lines was estimated to be about 106 eV and it takes into account the Gaussian experimental broadening for analysed energy range (about 70 eV) and the effective line broadening caused by its satellite structure reflecting the different number of electrons present in the high n-states while the X-rays are emitted.

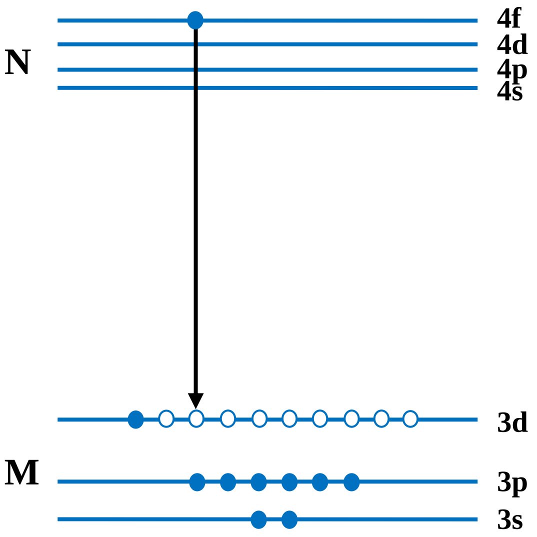

Figure 2. The diagram showing the electron configuration and 4f-3d transition in highly charged Xe^{35+} ion.

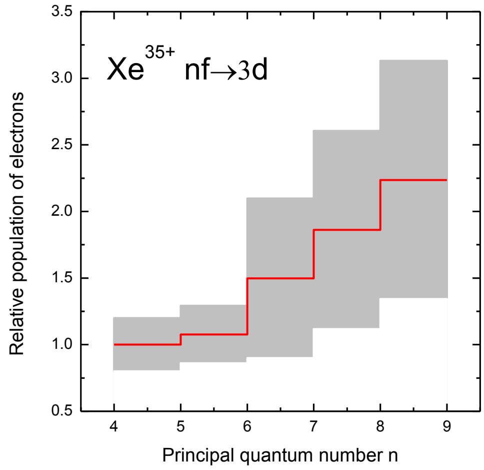

Figure 3. Dependence of the measured relative intensities of nf-3d X-ray transitions with respect to 4f-3d. The gray rectangles indicate the error bars.

The calculations based on Classical Over-barrier Model [7][8] suggests that in collision electrons from beryllium conduction band are resonantly captured into high Rydberg states (up to n=23). This hypothesis is consistent with analysis of the measured spectrum, where X-ray transitions from high n-states (up to n=20) to n=3 state are observed. The relative intensities of the strongest spectral lines in each series of hypersatellites were chosen to best describe the experimental spectrum. The results presented in figure 3 where normalised to the relative intensities predicted by hydrogen-like atoms model [9-10]. Because the total intensity of the line is proportional to the population of higher state, this graph carry information on a number of electrons at the higher shells (relative to the amount of electrons on the shell n=4). Analysis of both graphs (see figures 2 and 3) leads to a picture showing that after neutralization of HCI at a surface many electrons are in high Rydberg states, while the inner shells remains less populated or almost empty. This indicates in fact a formation of the "hollow atom" in the process of interaction of slow Xe^{35+} ions with Be foil.

4. Acknowledgments

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