Two-Photon Inner-Shell Ionization of atomic Xe

V. Richardson, J.T. Costello, D. Cubaynes\(^1\), M. Meyer\(^1\), S. Düsterer\(^2\), W.B. Li\(^2\), P.N. Juranic\(^2\), K. Tiedtke\(^2\), A.A. Sorokin\(^3\), M. Richter\(^3\), and H.W. van der Haart\(^4\)

NCPST and School of Physical Science, Dublin City University, Dublin, Ireland

\(^1\)LIXAM/CNRS, UMR8624, Centre Universitaire Paris-Sud, Bâtiment 350, 91405 Orsay, France

\(^2\)HASYLAB at DESY, Notkestr. 85, D-22607 Hamburg, Germany

\(^3\)Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany

\(^4\)Dept. of Applied Mathematics and Theoretical Physics, Queen’s University Belfast, Belfast, BT7 1NN, Northern Ireland

The interaction of intense XUV radiation from FLASH with atomic targets has revealed some new and surprising results related to multi-photon processes in the short-wavelength regime. In particular, two-photon double ionization processes have been studied extensively using a reaction microscope, which can provide information about the angular correlation of the outgoing electrons [1,2]. Ion yield experiments [3,4] have demonstrated the production of very high charge states, which are completely out of the reach of a one-photon process. Especially, for atomic Xe the potential role of the strong 4d-4/2(εf giant resonance has been highlighted. In the present study, we have started an investigation of the underlying processes by electron spectroscopy, concentrating here on the direct two-photon ionization of Xe.

The experiments have been performed at beamline BL3 at FLASH using a magnetic bottle type electron spectrometer (MBES) for the analysis of the kinetic energy of the photoelectrons [5] and a multi-layer mirror to refocus the FEL beam into the interaction volume (Fig. 1). A beam block in front of the mirror enabled us to determine the signal produced by the unfocussed incoming beam (diameter about 10 mm) and to extract in this way the electron spectrum corresponding to the strongly focused FEL beam only. FLASH was operated at 13.3 nm (93 eV) and provided up to about 60 \(\mu\)J pulse energy. In the focus region (beam diameter of about 5 \(\mu\)m) a field of some \(10^{15}\) W/cm\(^2\) was applied in that way. The pulse energy of the XUV pulses was permanently monitored by means of a gas monitor detector (GMD) installed in the beamline.

![Figure 1](image-url) Figure 1: Experimental set-up for the study of two-photon ionization of Xe atoms. A magnetic bottle type electron spectrometer was used for the electron analysis. Focussing of the FEL beam was achieved by a spherical multi-layer mirror, which produced a focal spot of about 5 \(\mu\)m in the interaction volume. Spectra were taken with the unfocussed and the unfocussed plus focussed FEL beam in the chamber.

For the unfocussed beam and/or for low intensities of the FEL beam one-photon ionization is the dominant process. Part of the corresponding electron spectrum is displayed in Figure 2a showing the 4d photolines at kinetic energies of 25.5 and 23.5 eV, which correspond to ionization of spin-orbit components 4d\(5/2\) and 4d\(3/2\), respectively. The corresponding N\(_{45}\)O\(_{23}\)O\(_{23}\) Auger lines are seen in the region 30-35 eV. This spectrum is quite similar to spectra recorded at synchrotron radiation sources, where even a much higher spectral resolution can be obtained. At higher kinetic energies,
some broad lines corresponding to the emission of 5p and 5s electrons are observed at about 80 and 70 eV, respectively.

When we used the multi-layer mirror to refocus the XUV beam into the interaction volume, some small additional lines show up at about 110-120 eV (Fig. 2b). In order to clearly observe these structures a retardation voltage of -90 V was applied to the entrance of the MBES preventing the low kinetic energy electrons from reaching the detector. These new features are attributed to a two-photon ionization process, mainly from the 4d shell in Xe. Spectra were recorded with and without Xe gas in the chamber in order to be able to determine the contribution of ionization from residual gas and of scattered light. In addition, the spectra recorded, when the spherical mirror was blocked, show only very small contribution from the second order light of the FEL radiation. As a final proof for the observation of a two-photon process, the integrated intensity of the broad line was measured as a function of the FEL pulse intensity showing a linear dependence in the double logarithmic plot with a slope of 2.

The detailed analysis of the structure is still in progress, since calculations have indicated the importance of the two-photon ionization of the 4p shell in Xe. This process would lead to the N_{22}O_{23}O_{23} Auger decay with prominent line structures around 112 eV [6]. These lines are probably not resolved in the present experiment, but may be responsible for the very broad line width, which exceeds by far the expected width given by the bandwidth of the FEL (about 2 eV) and the resolution of the electron spectrometer (about 1.5 eV).

We greatly appreciate the work of the scientific and technical team at FLASH. Support from the European Community: Contract RII3-CT-2004-506008 (IA-SFS), from Science Foundation Ireland (Frontiers), IRCSET and from the France-Ireland ULYSSES program is acknowledged.

References