X-ray spectroscopy of ultrafast-decaying core-excited ionic states in atoms

T Mazza[1,*] M Ilchen[1,2], T M Baumann[1], R Boll[1], A De Fanis[1], P Grychtol[1], V Music[1,2], Y Ovcharenko[1], D Rivas[1], N Berrah[3], B Erk[4], E Gryzlova[5], P Johnsson[6], M Kiselev[5], C Küstner-Wetekam[2], L Marder[2], M Martins[7], Ch Ott[8], S Pathak[9], Th Pfeifer[8], D Rolles[9], P Schmidt[1,2], A Grum-Grzhimailo[9] and M Meyer[1,*]

[1]European X-Ray Free-Electron Laser Facility GmbH, Holzkoppel 4, 22869 Schenefeld, Germany
[2]University of Kassel, Institute of Physics, Heinrich-Plett-Str. 40, 34132 Kassel, Germany
[3]University of Connecticut, Physics Department, Unit 3046 Storrs, CT 06269-3046, United States
[4]Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22671 Hamburg, Germany
[5]Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, 119991 Moscow, Russia
[6]Lund University, Department of Physics, Box 117, 221 00 Lund, Sweden
[7]University of Hamburg, Institute of Experimental Physics, Luruper Chaussee 149, 22761 Hamburg, Germany
[8]MPIK, Quantum Dynamics & Control, Saupfercheckweg 1, 69117 Heidelberg, Germany
[9]Kansas State University, Dept. of Physics, 116 Cardwell Hall Manhattan, KS 66506-2601, United States

Synopsis Results from the first soft X-ray experiment at European XFEL on non-linear photon-matter interaction will be presented. Electron spectroscopy reveals insight into the character of resonances in highly transient, core ion-ized neon ions and their relaxation dynamics.

Highly intense X-ray pulses from X-ray free-electron lasers (XFELs) allow to study in the short wavelength regime non-linear, photo-induced processes in atoms and molecules. These can include sequential and non-sequential multiphoton ionization and excitation processes. Sequential ionization processes in the X-rays involve core-shells and occur in competition with ultrafast relaxation via Auger emission; when the X-ray intensity is high enough, this competition becomes effective and the population of transient highly excited ions exposed to the radiation becomes significant, so that it is possible to perform a spectroscopic characterization on it. By using the intense pulses from the SASE3 soft X-ray undulators at European XFEL, we could, for the first time, study the core-hole excitation of transient, highly excited atoms by means of resonant Auger electron spectroscopy employing the Small Quantum Systems (SQS) instrument.

Neon was ionized at the 1s shell and,depending on the photon energy, either sequentially ionized to Ne^{2+} $1s^02s^22p^6$ or excited to different Ne^{+*} $1s^02s^22p^6np$ states within the same fs X-ray pulse. Thanks to the extremely efficient tunability of the SASE3 undulator, it was possible to scan the photon energy across the $1s^12s^22p^6 \rightarrow 1s^02s^22p^6np$ resonances with photon energy steps of 1 eV (much smaller than the bandwidth). The resulting Auger electron spectra were recorded by electron time-of-flight spectrometers.

The results of these measurements are compared to previous studies of single- photon processes populating the same final states [2] and with theoretical results based on R-matrix calculations.The comparison of the experimental results with the theoretical model allow to address the relevance of shake-up processes in the resonant Auger decay pattern for the particular case of the double core hole excited $1s^02s^22p^6np$ ionic state in comparison to the neutral $1s^12s^22p^6np$.

These results are benchmarking the performance of the SQS endstation at European XFEL and demonstrate the novel possibilities which have been opened up in particular for investigations of non-linear phenomena and ultrafast decaying transient states in the X-ray domain.

References

[1] Young L *et al* 2010 *Nature* **466** 56
[2] Goldsztejn G *et al* 2016 *Phys. Rev. Lett.* **117** 133001

* E-mail: tommaso.mazza@xfel.eu, michael.meyer@xfel.eu