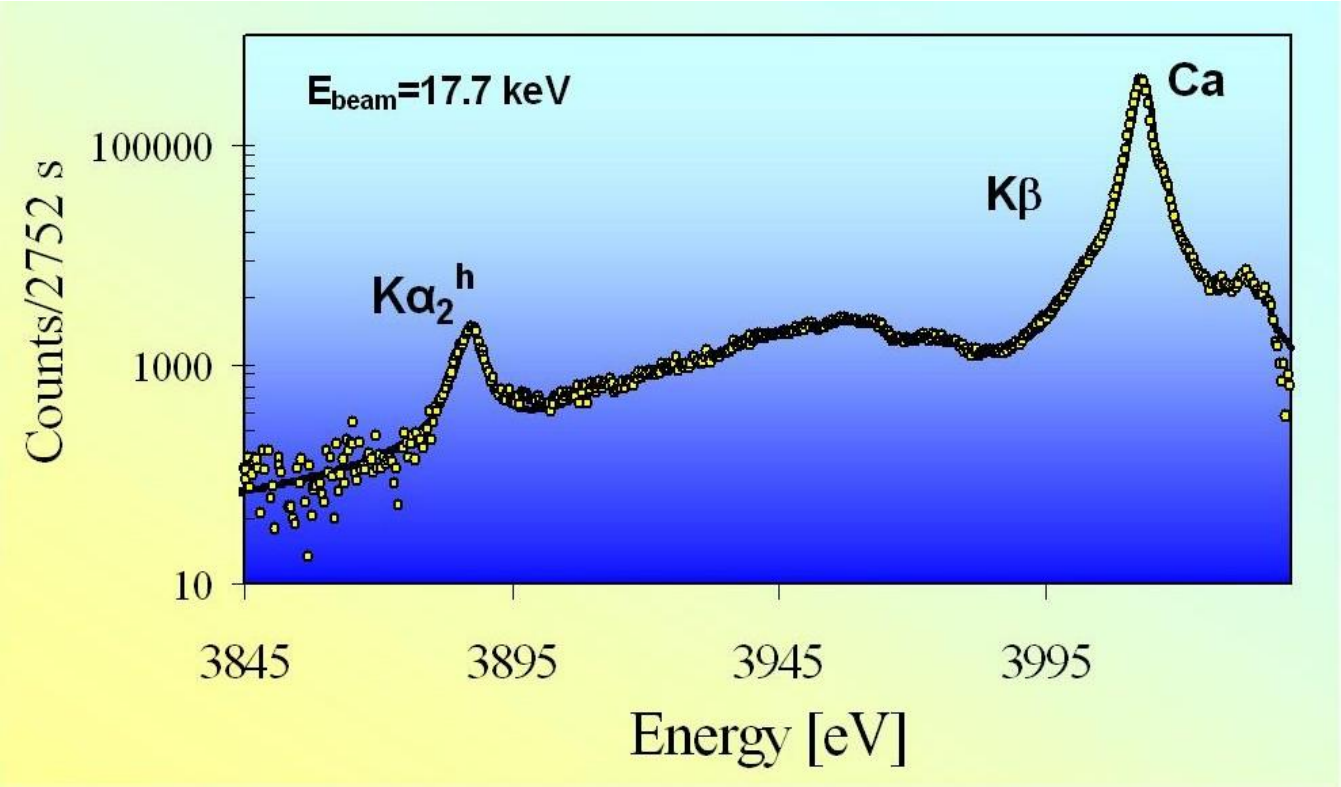
Hollow Atoms

Hollow K-shell atoms are atoms with an empty innermost shell and outer shell occupied. They may be created via K-shell double photoionization (DPI), by means of electron and α-particle impact, in ion-atom collisions and in nuclear α, β, electron capture (EC) decays. The double photoionization process has been a subject of intensive research both on the experimental and theoretical side and is still attracting considerable attention. With the advent of intense and energy tunable x-ray synchrotron sources there has been a renewed interest in hollow atoms. In particular, the investigation of the photon energy dependence of the DPI became possible.

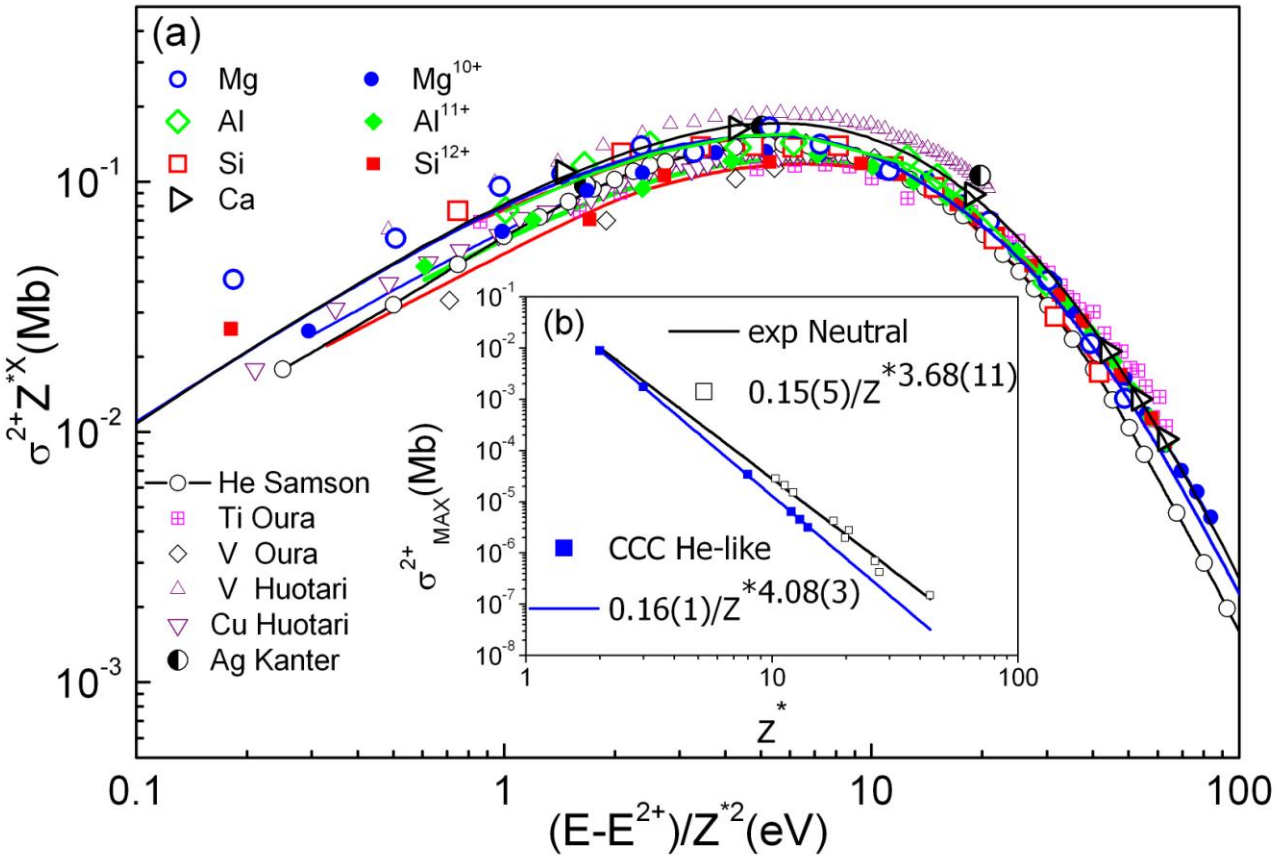
Because single-photon absorption and two-electron ejection is induced by only one single interaction of the photon with the bound electron, K-shell DPI is one of the most sensitive probes of electron correlation effects. Although these multielectron transitions were predicted in 1925 by Heisenberg, the quantitative description of electron-electron interactions beyond the simplest two-electron system, He, is still far from complete or satisfactory. Further, understanding the concept of correlation is not only important for atomic structure but also for a reliable theoretical description of a large number of physical systems and processes.

To shed new light on the nature of atomic correlation effects we have investigated the photon energy dependence of single-photon double K-shell ionization of low-Z atoms. The experiments were carried out at the European Synchtrotron Radiation Facility (ESRF), Grenoble, France, using monochromatic and energy-tunable synchtrotron radiation and the Fribourg von Hamos curved crystal x-ray spectrometer. The experimental method was based on the measurements of the high-resolution hypersatellite x-ray spectra following the radiative decay of the double K-shell vacancy states. Since for light elements the K hypersatellites are partly overlapping with the L-satellites of the diagram ($1s^{-1} \rightarrow 3p^{-1}$) transitions, the use of high-resolution was mandatory. The double-to-single cross section ratios were deduced from the relative intensities of the resolved hypersatellite ($1s^{-2} \rightarrow 1s^{-1}2p^{-1}$) to the diagram ($1s^{-1} \rightarrow 2p^{-1}$) x-ray transitions.



K-hypersatellite x-ray spectrum of Ca.

Physical mechanisms and scaling laws of the K-shell double photoionization were examined. The relative importance of the initial-state correlations and final-state electron interactions in K-shell DPI in many-electron atoms and two-electron ions was adressed. Further, to investigate the role of outer shell shell electrons in the K-shell DPI, the experimental K-shell DPI cross sections for hollow atom production are compared to those of the convergent close-coupling calculations (CCC) for the corresponding He-like ions.



(a) Scaled experimental DPI cross sections for Mg, Al, and Si compared to the scaled CCC calculations for He-like ions and experimental data for higher Z elements as a function of the scaled excess energy. A scaling exponent X of 4.08 along the He isoelectronic series and 3.68 for neutral atoms was used (see inset).

*(b) Shown are the power-law fits to the maximum of the double K-shell photoionization cross section as a function of Z^*. The error bars are smaller than the symbols. Experimental data are from the following References: J.A.R. Samson et al., Phys. Rev. A **57**, 1906 (1998), M. Oura et al., J. Phys. B **35**, 3847 (1998), S. Huotari et al., Phys. Rev. Lett. **101**, 043001 (2008), E.P. Kanter et al., Phys. Rev. A **73**, 022708 (2006).*

Our results suggest that the post-photoabsorption electron correlations are different for neutral and He-like ions. A semiemiprical universal scaling of the double photoionization cross sections with the effective nuclear charge for neutral atoms was established.