Shaking the Fundamentals of Physics: At the Limits of the Photoelectric Effect

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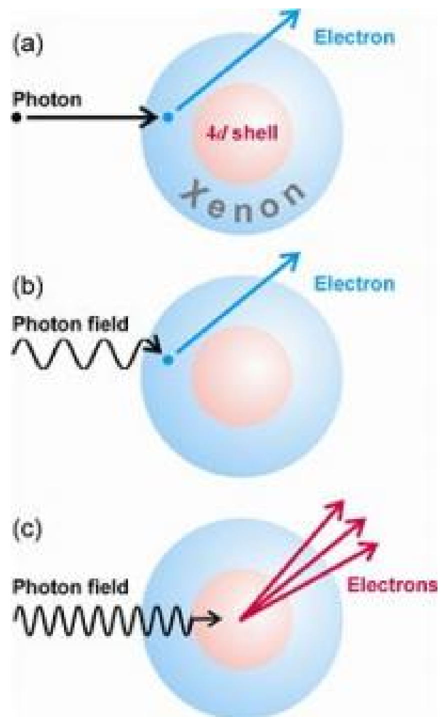

Photoionization of xenon: (a) classical photoelectric effect in the outer shell at low photon intensity, (b) strong-field single ionization in the outer shell by long-wave radiation at high intensity, (c) strong-field multiple ionization in the inner 4d shell by short-wave X-rays at high intensity. (Image: PTB)

With extremely short wavelengths and very high intensities, light-matter interaction seems to be different than previously accepted.

By way of the classical photoeffect, Einstein proved in 1905 that light also has particle character. However, with extremely high light intensities, remarkable things happen in the process. Scientists of the Physikalisch-Technische Bundesanstalt (Germany) have found this out with colleagues at FLASH in Hamburg, the first free-electron laser (FEL) for soft X-rays worldwide.

The current models based on Einstein's idea are simply described in such a way: A photon knocks an external electron out of an atom, provided that the photon energy is high enough. However, with wavelengths of only 13 nanometers and high radiation intensities of several petawatt per square centimeter something else - at least with some atoms - happens: With xenon, a whole light-wave packet immediately seems to knock out a huge number of internal electrons. This effect is strongly dependent on the material and not only on the characteristics of the exciting radiation, as accepted before. The work, which is currently published in the journal Physical Review Letters, has significance for future experiments of materials research at the new large X-ray laser facilities of the world.

The scientists actually wanted to develop methods for the radiometric characterization of X-ray lasers. They irradiated different gases to derive the laser strength from the ionization effect. The aim: with the laser well characterized was, for example, the testing of EUV lithography mirrors. The EUV lithography (EUV stands for extreme ultraviolet) at wavelengths in the range of 13 nanometers is considered as the future technology for the production of ever smaller computer chips.

However, during their experiments at FLASH, the new free-electron laser (FEL) in Hamburg, which currently allows the generation of EUV radiation and soft X-rays of the highest intensity in the world, they unexpectedly discovered things which concern the fundamentals of physics.

With the classical photoelectric effect (a), a single light particle (photon) of sufficient energy interacts with a single electron of the material. The process is energetically described by the Einstein equation (1905) and demonstrates the quantum structure of light. Only at very high intensities, does the multiphoton ionization occur, a process which is described in the extreme case of highly intensive ultra-short light flashes as emitted by long-wave femtosecond lasers, again, in the wave picture of light (b).

Nevertheless, the suitable theoretical models fail in the short-wave X-ray regime as shown by the experiments in Hamburg in which, for the first time, soft X-ray irradiance levels of several petawatts per square centimeter were achieved by strong beam focusing. The comparative quantitative studies prove that the degree of light-matter interaction and, thereby, the nature of the X-ray light are decisively determined by the structure of the atom and correlations in, above all, inner electron shells.

In the extreme case (xenon), a whole wave packet of photons seems to lead to the simultaneous emission of several inner electrons (c).

More information: Extreme ultraviolet laser excites atomic giant resonance. M. Richter et al., *Phys. Rev. Lett.* (2009) - online publication expected: April 27, 2009.

Photoelectric effect at ultra-high intensities. A. A. Sorokin et al., *Phys. Rev. Lett.* 99, 213002 (2007)

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