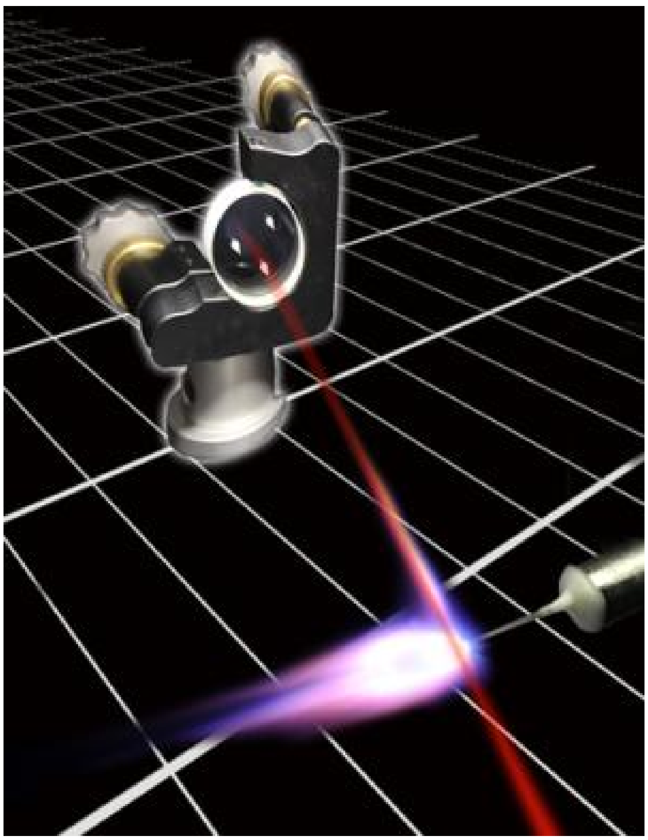
Electron spectroscopy: Not just snapshots, real movies

July 15 2013, by Thorsten Naeser



Artist's impression of the experiment: A pulse of laser light (coming from the right, indicated in red) hits a cloud of argon atoms. The atoms absorb the light energy and re-emit it in the form of trains of attosecond pulses, at a rate of 78 million per second. A specially constructed pierced mirror with a tiny aperture (upper left) serves to capture the pulses of extreme ultraviolet radiation. The high repetition rate will make it possible to produce high-resolution movies of ultrafast alterations in the motions of electrons in atoms and molecules. Credit: Thorsten Naeser

(Phys.org) —Physicists based at LMU Munich and the Max Planck Institute for Quantum Optics have developed a laser configuration that allows them to "film" the motions of electrons.

Electrons are no slouches. In fact, they move so fast that they are hard to pin down. Nowadays these elementary particles can indeed be imaged, but what one gets are single, isolated snapshots. So the dispersion of free electrons over time has so far been impossible to observe directly. But now research groups based at LMU's Laboratory for Attosecond Physics (LAP) and the Max Planck Institute for Quantum Optics (MPQ) in Garching, in collaboration with colleagues at Friedrich Schiller University in Jena have come up with a laser configuration that will make it possible to follow the dynamics of electrons essentially by filming them. The team has used a high-power laser to produce trains of attosecond pulses at a rate of 78 million per second, with each train containing around 20 individual flashes, each lasting less than a femtosecond. With this high repetition rate, it should be possible to characterize the behavior of electrons, whose quantum states fluctuate extremely rapidly, with greater efficiency than ever before. The breakthrough thus heralds a new era in the observation of this type of elementary particle.

Stroboscopic photography is a special technique that allows one to freeze the motion of moving objects. The trick is to trigger the flash several times while keeping the shutter open. The effect of the multiple exposure is spectacular. The object is captured several times on a single image, stopping its motion at different points in its trajectory.

Physicists who wish to understand ultrafast processes in atoms and molecules can`t help feeling a little envious when they come across conventional images taken with the help of a stroboscope. In the world of femto- or attosecond physics, it has only been possible to take single snapshots of the motion of ultrafast particles, such as electrons. Such snapshots are taken with the help of light flashes generated with the aid of ultrashort pulses of laser light. But the quantum dynamics of electrons can change in a matter of attoseconds – an attosecond is a billionth of a billionth of a second (10-18 sec) – too fast to be captured as sharp images with these exposure times. Electron configurations in atoms also fluctuate on attosecond time-scales.

With the help of a new technique developed by a team of laser physicists led by Professor Ferencz Krausz and Dr. Ioachim Pupeza, it should soon be possible to monitor the dynamics of quantum particles in greater detail and with higher temporal resolution, using an approach akin to stroboscopic imaging.

Using a high-power ytterbium fiber laser as their light source, the team has been able to generate trains of attosecond pulses at a rate of 78 million per second (78 MHz). Each train comprises about 20 individual attosecond flashes. The laser pulses used to create the attosecond flashes were first coherently enhanced in a so-called optical resonator – a system of mirrors forming a cavity in which the light is reflected back and forth multiple times before escaping. Each time a wave pulse hits a particular mirror, it is amplified by the synchronous addition of a succeeding pulse. This superimposition of waveforms allowed the scientists to enhance the amplitude of the initial pulse, which was about 50 femtoseconds long (a femtosecond is a millionth of a billionth of a second or 10-15 sec) by a factor of 250, while improving its stability.

These pulses were then focused on a target made up of a cloud of argon atoms. The atoms absorb the energy and rapidly re-emit it in the form of attosecond flashes of radiation. These ultrashort pulses are then selectively coupled out of the resonator by means of a clever filtering method. This involved by directing them at a pierced mirror with an aperture that was just big enough to let the attosecond pulses pass through without significant perturbation.

In this way, the scientists were able to generate attosecond pulse trains at the rate with which the ytterbium fiber laser emitted light pulses, 78 MHz. The attosecond flashes thus produced consist of extreme ultraviolet radiation, with wavelengths of between 10 and 100 nm. Moreover, the radiation is coherent – the light waves oscillate in phase – and the energy of the light particles (photons) is around 100 eV – higher than has ever been achieved at such repetition rates.

Taken together, these features have the potential to revolutionize research on the microcosmos with the help of optical photons. The extremely high rate of data acquisition will, for the first time, make it possible to follow the dynamic behavior of electrons, in the same way as photographs taken with stroboscopic illumination enable one to stop the motion of macroscopic objects.

The researchers intend to pursue this approach still further, with a view to increasing the power of the laser pulses while reducing their duration. Ultimately, they hope to produce isolated attosecond flashes instead of trains of pulses. Furthermore, they wish to enhance the energy of the photons that make up the attosecond pulses to reach the so-called "water window" at 280 eV. This in turn would allow them to observe the microscopic behavior of biomolecules with very high temporal resolution, i.e. to make molecular movies.

More information: Compact high-repetition-rate source of coherent 100 eV radiation, *Nature Photonics*, 7 July 2013, DOI:10.1038/nphoton.2013.156

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