NEWS

In the Blink of an Eye

Researchers want to freeze-frame the workings of atoms with laser pulses just billionths of a billionth of a second long. But first they must prove they really can produce a blast that short

To photograph something that happens very quickly, you need a camera with lightning-fast shutter speed. But to study how molecules behave and interact, no shutter is fast enough. Instead, for a couple of decades, researchers have used flashes of laser light little longer than a femtosecond; that's just a millionth of a billionth of a second. Now they want to go even quicker. Over the past few years, scientists have passed the femtosecond frontier and are measuring their pulses in attoseconds: billionths of a billionth of a second.

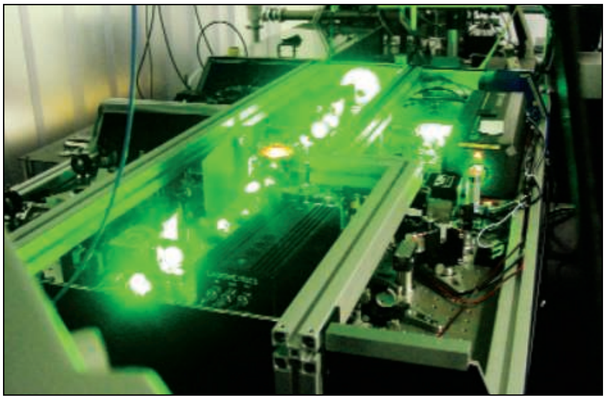
Such flashes should allow researchers to see inside an atom by freeze-framing the motion of an electron around the nucleus. They haven't got there yet—researchers are still learning how to produce the laser pulses cleanly and to measure their length—but they are looking forward to their first snapshots of the atom's interior. "I hope we will discover something we haven't even dreamed of," says Ursula Keller of the Swiss Federal Institute of Technology in Zurich.

A host of phenomena in molecules, atoms, and even solid matter takes place at attosecond time scales. "The dynamics of the electrons [during ionization] is much faster than a femtosecond. At one point they have to decide on which ion they go and sit, and this happens very fast," says Keller. After a decade of work, researchers are only just getting a glimpse of such processes. "At the moment there are very few systems that are able to make these measurements," says Ian Walmsley of the University of Oxford.

It's impossible to make an attosecond pulse with visible light because its wavelength lasts more than a femtosecond, and so the pulse would be less than a wavelength long. But in the early 1990s, several researchers suggested a way to make short pulses using shorter wavelengths, in the extreme ultraviolet (XUV) ranges. The technique, known as high-order harmonics generation, involves hitting atoms of a rare gas with a powerful femtosecond pulse from an infrared laser. As the electric field component of the infrared pulse oscillates back and forth, it rips electrons off the atoms, and then it smashes them back into the nucleus. As the electrons return to the ground state, they emit a burst of radiation that is a combination of higher harmonics of the applied infrared frequency. The result is a sharp attosecond-long XUV pulse.

Anne L'Huillier, now at Lund University in Sweden, pioneered this technique during the 1990s while working at the French Atomic Energy Commission's Saclay research center at Gif-sur-Yvette. But at first, researchers were only able to make strings of attosecond pulses about 1.3 femtoseconds apart. To get a snapshot of events inside the atom, they needed clean, isolated attosecond pulses. Part of the problem was that the infrared pulses used to make the attosecond flashes were themselves untidy and chaotic. The shape of the pulses—how the amplitude of the radiation rose to a peak then subsided again—bore no relation to the electromagnetic waveform that oscillated within it.

Researchers needed infrared pulses in which the maximum of the electromagnetic wave coincides with the maximum of the pulse envelope. Only that peak electromagnetic wave has the intensity to generate an XUV burst. In 1999, Keller's group proposed a way to make such a wave using a feedback mechanism that detects the state of the electromagnetic wave and tweaks the laser that produces it. But it was Ferenc Krausz of the Max Planck Institute for Quantum Optics (MPQ) in Garching, Germany, who turned theory into reality. In 2003, while he was at the Technical University of Vienna, his group reported neat single XUV pulses. "The Vienna-MPQ group is now clearly the leading group in this area. They have a system that works, and it works well," says Walmsley.



The light fantastic. Superfast laser pulses could open a new window on the workings of matter.

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Although the pulses were undoubtedly short, Krausz and his team still had to prove that they were less than a femtosecond long. Earlier this year Krausz employed a technique known as a "streak camera" to measure the pulse length. He and his colleagues directed an XUV flash at a target of neon atoms. The pulse tears electrons from these atoms, and then the electric field of a second, infrared light pulse sweeps them sideways into an electron detector. From the energy distribution of these electrons, the researchers could determine the duration of the x-ray pulse—a speedy 250 attoseconds.

To demonstrate what attosecond pulses can do, Krausz and his team used them to make a waveform of light visible (*Science*, 27 August, p. 1267). In a technique they've dubbed the "light oscilloscope," the team ejected electrons from some atoms by blasting them with an attosecond XUV pulse and then hit those electrons with a femtosecond infrared pulse. During the small time window of 250 attoseconds, the electric field associated with the infrared light wave accelerates these electrons, which are then captured by a detector. From their arrival times and energies, the team could deduce the shape of the infrared light wave.

Several groups in Europe, North America, and Japan are now gearing up to do similar research, says Walmsley. "The tools and techniques of attosecond metrology are now really ready," says Krausz. One such team is led by theoretical physicist Thomas Brabec of the University of Ottawa. "We are working on potential applications in atoms and clusters … because [clusters] are the transition between atoms and condensed matter," he says. And Ahmed Zewail of the California Institute of Technology in Pasadena, who received the 1999 Nobel Prize in chemistry for his pioneering work in femtochemistry, is now also looking through this new window at matter in a state never seen before: "If you can catch any system in a very short time, then you are far from the equilibrium state of these systems, and in refining more and more the time resolution, you will find some interesting phenomena," says Zewail.

–ALEXANDER HELLEMANS

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