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Laser-created temporal lens could lead to movies of molecular processes

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The first picture is of a baseball with the camera poorly focussed so the image is blurred. The second is a focussed fast image and the last one is a focussed but "slow" image of a rotating ball so that the image is streaked. This illustrates the difference between a blurred and streaked image and illustrates why stroboscopic illumination of moving things is necessary to see what is going on. (Image credit: Herman Batelaan)

(PhysOrg.com) -- Finding a way to observe and record the behavior of matter at the molecular level has long been a holy grail among physicists. That ability could open the door to a wide range of applications in ultrafast electron microscopy used in a large array of scientific, medical and technological fields.

Now, a team at the University of Nebraska-Lincoln has figured out a possible way to do that. Working in collaboration with Nobel laureate Ahmed Zewail (chemistry, 1999) of the California Institute of Technology in Pasadena, they developed mathematical models to show that laser beams create ultra-high-speed "temporal lenses" that would be capable of making "movies" of molecular processes. The finding was published in the June 15-19 online edition of the Proceedings of the

National Academy of Sciences.

The "lenses" in question are not made of glass like those found in standard tabletop microscopes. They're created by laser beams that would keep pulses of electrons from dispersing and instead focus the electron packets on a target. The timescales required, however, are hardly imaginable on a human scale -- measured in femtoseconds (quadrillionths of a second) and attoseconds (quintillionths of a second).

Herman Batelaan, associate professor of physics at UNL, said the process is analogous to filming the flight of a thrown baseball. First, the camera lens must be focused properly or the ball will appear blurred. Second, the camera has to have a fast shutter speed or the seams of the ball will appear streaked. But the analogy stops there.

Two other analogies help illustrate the timescales Batelaan and his colleagues are grappling with. A standard comparison is that one attosecond is to one second as one second is to the age of the universe. Another is that one attosecond is to one second as the volume of one grain of sand is to the volume of all the water in all of the oceans of the world.

"The timescales involved here are daunting," Batelaan said. "A crisp image of the seams of a thrown baseball can be made with a strobe pulse of about one 10 millionth of a second. Taking a crisp image of an atom in a molecule is much more demanding. Pulses that are a billion times shorter than that are needed. Anything produced to date is 50 times slower than that, and making movies of most molecules has stayed out of reach.

"The new idea is that a temporal lens exists and obeys the same laws as a spatial lens. That's what we showed in this paper. Nobody had ever used a temporal lens to get a higher resolution."

The physicists modeled two types of lenses. One was a temporal "thin" lens created using one laser beam that could compress electron pulses to less than 10 femtoseconds. The second was a "thick" lens created using two counterpropagating laser beams that showed the potential of compressing electron pulses to reach focuses of attosecond duration.

"The thick lens will give the best value, but it's much more complex, because the attosecond regime is three orders of magnitude smaller than the femtosecond regime," said Shawn Hilbert, the paper's lead author and a May Ph.D. graduate studying and researching under Batelaan.

"It's great that we were able to take a very simple idea -- at least in physics -- and produce a paper like this," Hilbert said. "The lensmakers equation is something you learn in intro to optics, so pretty much any undergrad in physics learns this stuff. But now we've applied it to time, which no one has ever thought of in this way before. You could explain this to intro undergraduate students and they would get the idea. It's very simple, but it's also very powerful."

In addition to Hilbert (a native of Hanover, Pa., who will begin a tenure-track faculty position at Texas Lutheran University in the fall) Batelaan and Zewail, the other co-authors of the paper are Cornelis "Kees" Uiterwaal, associate professor of physics at UNL, and Brett Barwick, a postdoctoral scholar with Zewail at Cal Tech. Barwick earned his Ph.D. at UNL, studying quantum optics with Batelaan from 2002 to 2007, before going on to Zewail's lab, and provided the critical bridge to bring the collaboration about.

"He (Zewail) called us and said, 'Hey, do want to work with us?'" Batelaan said. "He knew that with Brett, we had developed techniques that allowed us to explore this kind of research. He asked if we could go further with this application because the Cal Tech people want to use it to make movies of molecular processes.

"We've been looking through cloudy lenses in a pair of glasses. Now, we've figured out that there is such a thing as clear glasses. I think it's really cool."

Provided by University of Nebraska-Lincoln (news : web)

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