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UNL physicists model potential 4-D imaging technique

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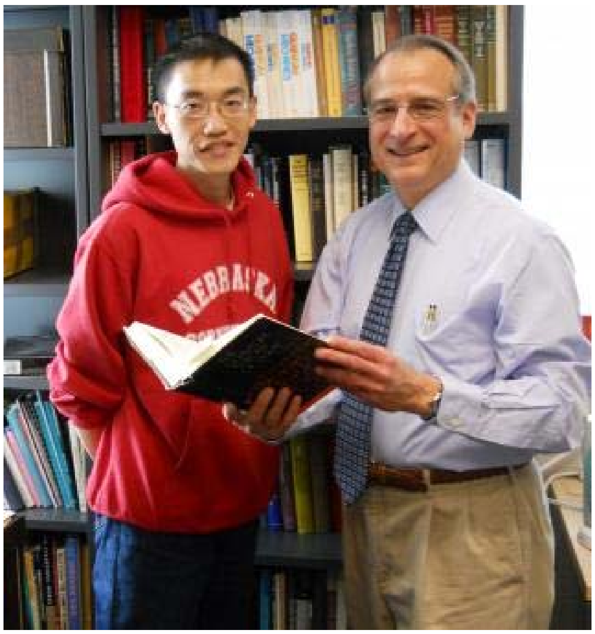
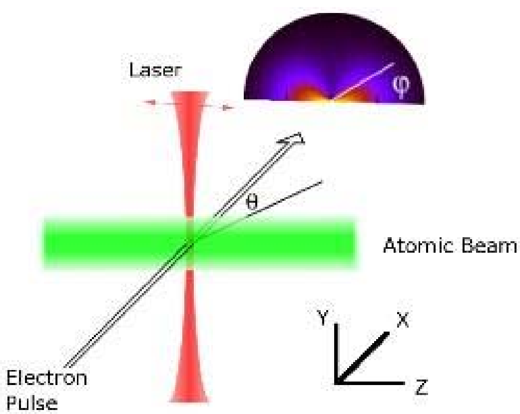


Hua-Chieh Shao and Anthony Starace



An illustration of an experiment modeled by Hua-Chieh Shao and Anthony Starace. It shows the 110-attosecond electron pulse sent through a beam of hydrogen atoms (green) excited by a laser (red). The distribution pattern of the scattered electrons is in the background.

A long-standing goal of science is to be able to understand how matter behaves at the atomic and subatomic level.

How electrons rearrange when atoms or molecules come together is the essence of chemistry, and the ability to manipulate those rearrangements is the goal of the emerging sphere of nanotechnology. A fuller understanding could lead to enormous scientific and technological breakthroughs.

Unfortunately, significant problems confront scientists and engineers in attacking the question. Not only are atoms and molecules very small, requiring highly specialized equipment to "see" them, everything at the atomic level happens very, very fast. For example, an electron goes around the nucleus of an atom once every 150 attoseconds -- that's around one 10 millionth of a billionth of a second, far too quick for the human eye or any existing equipment to detect.

Scientists have a good understanding for simple chemical combinations, but not for complex entities like biological molecules. And nanotechnologists essentially operate in the blind in the sense that they are not yet able to watch while the nanostructures they construct are being assembled. They only know if they have succeeded after the fact.

Nothing exists to allow scientists and engineers to see those electronic processes, but University of Nebraska-Lincoln physics graduate student Hua-Chieh Shao and his adviser, theoretical physicist Anthony Starace, have modeled a four-dimensional imaging technique that could lead to a breakthrough. They report their findings this week in the online edition of Physical Review Letters. Their paper will appear in the Dec. 31 print edition of the journal. The research was supported in part by funding from the National Science Foundation and the Nebraska Research Initiative.

Starace said he and Shao were intrigued by research that his UNL colleagues Herman Batelaan and Kees Uiterwaal were doing with Nobel laureate Ahmed Zewail of Cal Tech on what Zewail terms four-dimensional imaging -- imaging electronic processes in both space and time with very energetic, but extremely short, pulses of electrons.

"We got excited about this idea and decided to do what I think are among the first calculations, if not the first, to show what you would see," said Starace, University Professor and George Holmes Professor of Physics.

Deriving analytic formulas as far as possible and then writing computer programs to evaluate the formulas and analyze the results, Shao and Starace determined what would happen if electron pulses of 110 attoseconds were fired at targets excited by a laser field. Their first target was the hydrogen atom, with one proton and one electron. Their second target was the tritium molecule, a hydrogen isotope with one electron and two nuclei.

In both instances, they found patterns in the distribution of scattered electrons that could be used to track changes in the target charge distribution over time -- in other words, how the position of the electrons was changing.

"These are sort of benchmark results showing this new technology that Zewail has called four-dimensional imaging," Starace said "We've shown among the first results in a realistic calculation that one could see for both an atom and a molecule. We made some assumptions (in the tritium calculations), but it's a fairly realistic picture of how electrons move in molecules."

It remains for experimentalists to develop the technique.

"Herman Batelaan and Kees Uiterwaal are working in collaboration with Zewail to develop the short electron pulses and our newest faculty member, Martin Centurion, has been talking with us about what experiments he may be able to do that would provide evidence of time-dependent electron motion. He does experiments with short pulses of electrons, but much longer than the pulses which we considered here," Starace said.

"I hope this will give added incentive to pursue this technology because we've shown that it can provide information that no other technique can provide. So now it's up to experimentalists to develop the tools. Scientifically, there's nothing stopping the development of the tools except money and manpower, as usual."

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Associated Media Files:

- Hua-Chieh Shao and Anthony Starace
- An illustration of an experiment modeled by Hua-Chieh Shao and Anthony Starace. It shows the 110-attosecond electron pulse sent through a beam of hydrogen atoms (green) excited by a laser (red). The distribution pattern of the scattered electrons is in the background.

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