Physicists observe key minuscule molecular interactions in ultra-fast atomic processes

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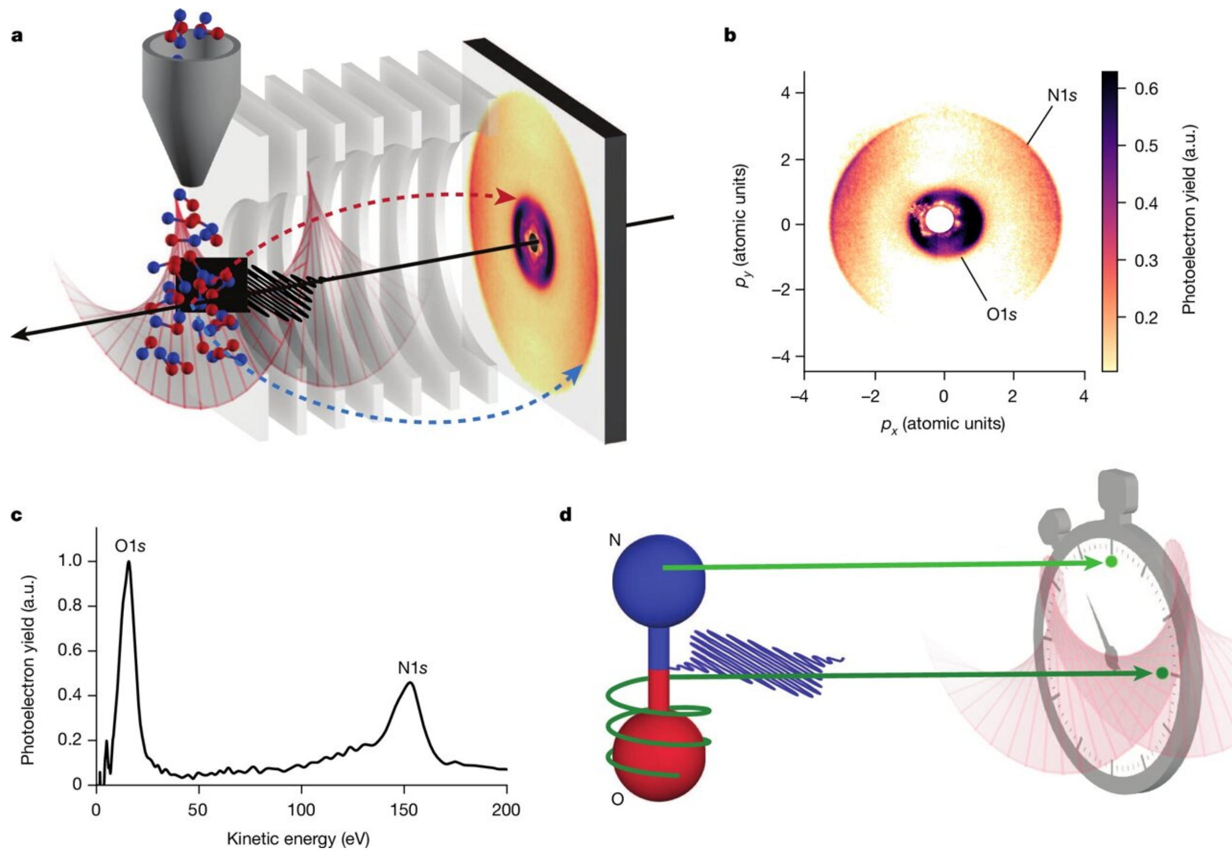

Experimental schematic. Credit: *Nature* (2024). DOI: 10.1038/s41586-024-07771-9

An international team of scientists is the first to report incredibly small time delays in a molecule's electron activity when the particles are exposed to X-rays.

To measure these tiny high-speed events, known as attosecond delays, researchers used a laser to generate intense X-ray flashes that allowed them to map the inner workings of an atom.

Their findings revealed that when electrons are ejected by X-rays, they interact with another type of particle called the Auger-Meitner electron, causing a secondary pause that's never been detected before. These results have implications for a wide range of research fields, as learning more about these interactions can reveal novel ideas about complex molecular dynamics, said Lou DiMauro, co-author of the study and a professor of physics at The Ohio State University.

"X-rays are interesting probes of matter," DiMauro said. "You could use them to take a series of stop-action snapshots of a molecule as it evolves before or during a chemical reaction."

The study was recently published in *Nature*.

While there have been many noteworthy leaps in scientists' ability to study attosecond delays using ultraviolet light over the past two decades, for years it was a task made all the more challenging due to the scarcity of advanced tools needed to produce them.

It was so difficult that Pierre Agostini, an emeritus professor of physics at Ohio State, was awarded the 2023 Nobel Prize in Physics for his past work developing techniques to study electron dynamics using pulses of light that last for hundreds of attoseconds, a unit of time equivalent to one quintillionth of a second.

It wasn't until relatively recently that new technologies such as the Linac Coherent Light Source (LCLS), a massive free electron laser device at

Stanford University's SLAC National Accelerator Laboratory, made these pulses much easier to create and visualize in the lab, said DiMauro.

Using the LCLS, the team studied how electrons inhabit a nitric oxide molecule, focusing on the electron particles that reside near the atom's oxygen core. They found that there were unexpectedly large delays that ranged up to 700 attoseconds, a pattern that suggests more complicated factors could be at play when determining what causes them, said Alexandra Landsman, a co-author of the study and professor of physics at Ohio State.

"We looked at what happens when you take out the electron from deep inside an atom, and what surprised me was how complex the dynamics of those deeply bound electrons were," said Landsman. "This means that behavior is much more complex than scientists thought, and we need better theoretical descriptions to fully describe the light-matter interaction."

Yet despite more research being needed to further understand the structure of these interactions, uncovering formerly hidden details about them also gives scientists new insights to consider, said DiMauro.

For example, if scientists can get a better grasp on intra-particle behavior, some experts speculate that their discoveries could be vital to breakthroughs for early cancer detection technologies, such as being able to use molecular markers to diagnose blood cancers or detect malignant tumors.

Furthermore, this paper suggests that, combined with theoretical models, researchers could use advances in attosecond science to glimpse matter on some of the smallest scales imaginable, as well as study in greater detail many broader mysteries of the physical universe.

"I'm looking forward to seeing how we use attosecond pulses to learn more about science, engineering or nature in general," said DiMauro. "Because what's described in this paper is an indication of a field that's really going to blossom."

More information: James Cryan, Attosecond delays in X-ray molecular ionization, *Nature* (2024). DOI: 10.1038/s41586-024-07771-9 . www.nature.com/articles/s41586-024-07771-9

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