Electron movements in liquid measured in super-slow motion

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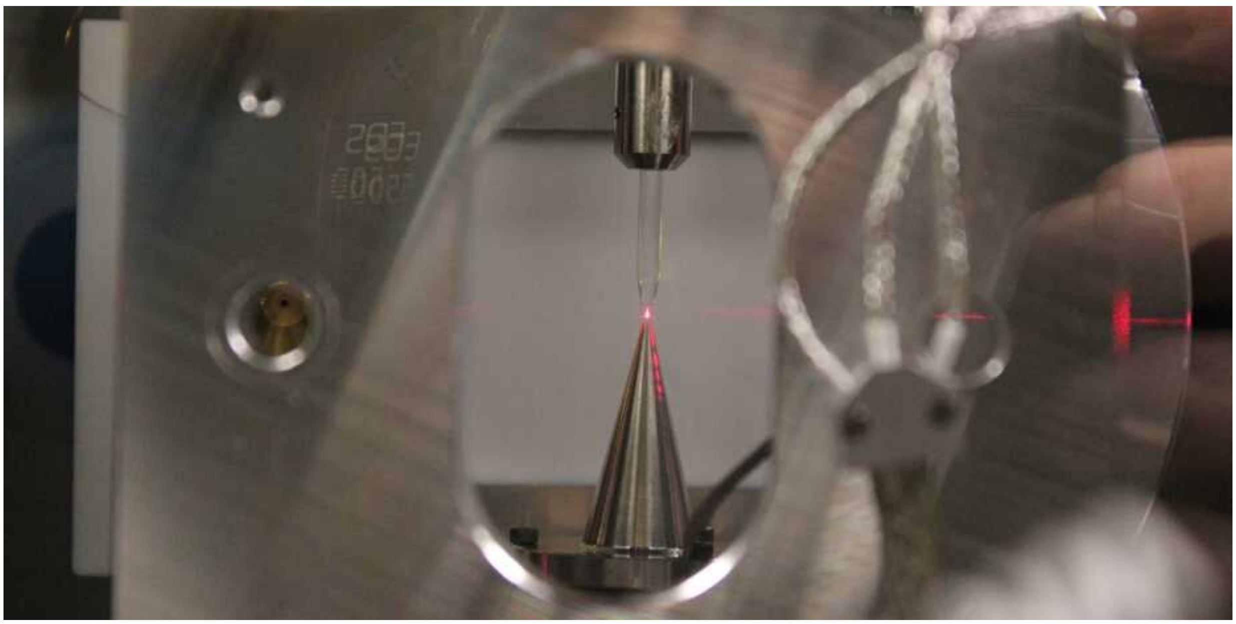

The scientists inject water from above into the analysis chamber, where it forms a short microjet that meets a laser beam. Credit: ETH Zurich / Inga Jordan

Electrons are able to move within molecules when they are excited from outside or in the course of a chemical reaction. For the first time, scientists have now succeeded in studying the first few dozen attoseconds of this electron movement in a liquid.

To understand how chemical reactions begin, chemists have used super-slow-motion experiments for years to study the very first moments of a reaction. These days, measurements with a resolution of a few dozen attoseconds are possible. An attosecond is $1x10^{-18}$ (one quintillionth) of a second, i.e., a millionth of a millionth of a millionth of a second.

"In these first few dozen attoseconds of a reaction, you can already observe how electrons shift within molecules," explains Hans Jakob Wörner, professor at the Laboratory of Physical Chemistry at ETH Zurich. "Later, in the course of about 10,000 attoseconds, or 10 femtoseconds, chemical reactions result in movements of atoms up to and including the breaking of chemical bonds."

Five years ago, the ETH professor was one of the first scientists to detect electron movements in molecules on the attosecond scale. However, up to now, such measurements could be carried out only on molecules in gaseous form because they take place in a high-vacuum chamber.

Delayed transport of electrons from the liquid

After building novel measuring equipment, Wörner and his colleagues have now succeeded in detecting such movements in liquids. To this end, the researchers made use of photoemission in water: They irradiated water molecules with light, causing them to emit electrons that they could then measure. "We chose to use this process for our investigation because it is possible to start it with high temporal precision using laser pulses," Wörner says.

The new measurements also took place in high vacuum. Wörner and his team injected a 25-micrometer-thin water microjet into the measuring chamber. This allowed them to discover that electrons are emitted from water molecules in liquid form 50 to 70 attoseconds later than from water molecules in vapor form. The time difference is due to the fact that the molecules in liquid form are surrounded by other water molecules, which has a measurable delay effect on individual molecules.

Important step

"Electron movements are the key events in chemical reactions. That's why it's so important to measure them on a high-resolution time scale," Wörner says. "The step from measurements in gasses to measurements in liquids is of particular importance, because most chemical reactions—especially the ones that are biochemically interesting—take place in liquids."

Among those, there are numerous processes that, like photoemission in water, are also triggered by light radiation. These include photosynthesis in plants, the biochemical processes on our retina that enable us to see, and damage to DNA caused by X-rays or other ionizing radiation. With the help of attosecond measurements, scientists should gain new insights into these processes in the coming years.

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