Physicists Ponder Atoms Without Nuclei

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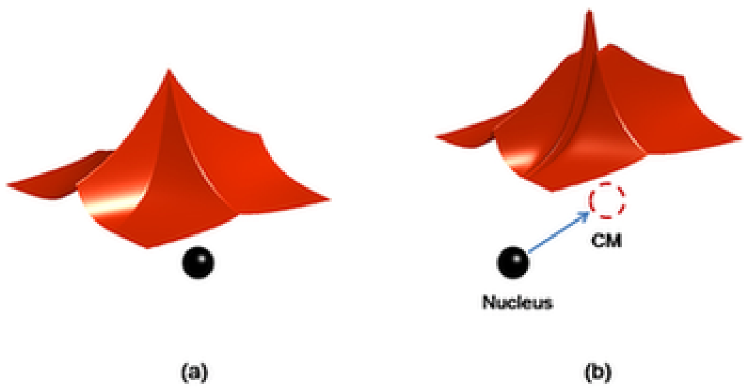

This illustration ashows the absolute value of the real part of the two-electron wave function for the H-initial state (a) before and (b) after an attosecond full-cycle pulse with a half-cycle momentum transfer equal to 10 atomic units and pulse duration equal to 0.6 atomic units. The arrow in (b) points in the direction in which the wavepacket is displaced with respect to the nucleus and the CM denotes the center of mass of the wavepacket. The small cut in the wavepacket in (b) is due to the electron-electron repulsion in the continuum. Image Credit: Darko Dimitrovski.

You might remember learning in sixth grade science class that isotopes are atoms that have lost or gained a few neutrons, and ions are atoms that have lost or gained a few electrons. But what about an atom that has lost its entire nucleus – when essentially all that remains are the electrons whizzing around in their defined orbits?

What to call such a system is not yet an urgent matter, since, for now, an atom without a nucleus is just a hypothetical concept. But physicists

John Briggs and Darko Dimitrovski from the University of Freiburg in Germany have recently described how such an atom might be created with the use of an attosecond laser. Capable of generating pulses that last just one billionth of a billionth of a second (10^{-18} seconds), an attosecond laser could possibly "detach" the electrons from an atom and – keeping their shape largely intact – remove them from being centered around the nucleus.

"I would not call it an 'atom,'" Briggs told *PhysOrg.com*. "Maybe an 'atom without a nucleus' or a 'filleted atom.' However, one should not forget that when several electrons are involved, once the nucleus is away, the electrons will repel themselves, and the 'atom' will be destroyed. Nevertheless, coincident detection of the electrons should allow reconstruction of the initial wavepacket."

Briggs said that he is not aware of the idea of an atom without a nucleus being proposed before. But such a thing could potentially be created because the duration of an attosecond laser pulse is much shorter than the orbital time of an atom's ground-state electrons. In a hydrogen atom, for example, an electron takes about 24 attoseconds to orbit the nucleus. Besides being short, the attosecond laser pulse must also be very strong, with an electric field equal to or greater than the nuclear field experienced by a bound electron.

The researchers propose that a single short (10-attosecond), strong (10^{18}-watt) laser pulse interacting coherently with the ground electrons could be used to remove all the electrons from an atom, completely ionizing the atom. In the first half-cycle of a pulse, several atomic units of momentum would be transferred, causing the electrons to accelerate away from the nucleus without changing the form of their initial wavefunction.

Normally, an electron wavepacket that leaves an atom spreads out and loses its shape, and the electrons quickly repel each other and fly apart. However, due to the extremely short attosecond pulse, the wavepacket has almost no time to spread.

Although a single half-cycle pulse can produce this wavepacket, electromagnetic theory shows that a half-cycle alone cannot be produced. So the researchers use the second half-cycle pulse to stop the electron wavepacket from moving away from the nucleus, producing a stationary atomic electron cloud spatially distant from its nucleus. Instead of being centered around the original nucleus, the wavepacket has shifted and is centered around the pulse’s mean momentum.

The researchers explain that this scheme could apply not only to single- or multi-electron atoms, but also to molecules. The greatest challenge, of course, is in building an attosecond laser with such a short, strong pulse.

A sufficient attosecond laser – once it exists – could enable researchers to test Briggs and Dimitrovski’s proposal. Using different half-pulses, researchers could create atoms without nuclei, as well as slow down electron wavepackets for extraction by detector fields.

“We conceived this as a ‘sexy’ little experiment,” Briggs explained. “However, the real message of the paper is that one should be able to fully ionize an atom or molecule (or even clusters of atoms or plasmas) and then control and manipulate, by further half-cycle momentum kicks, the state of the continuum electron wavepacket. The possibility of observing rather directly the spatial bound-state atomic wavefunction moving nucleus-free, essentially undistorted, is just one example of this general technique that the development of strong attosecond lasers will make realizable.”

More information: Briggs, John S.; and Dimitrovski, Darko. “Ionization in attosecond pulses: creating atoms without nuclei?” *New Journal of*

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