New path suggested for nuclear fusion

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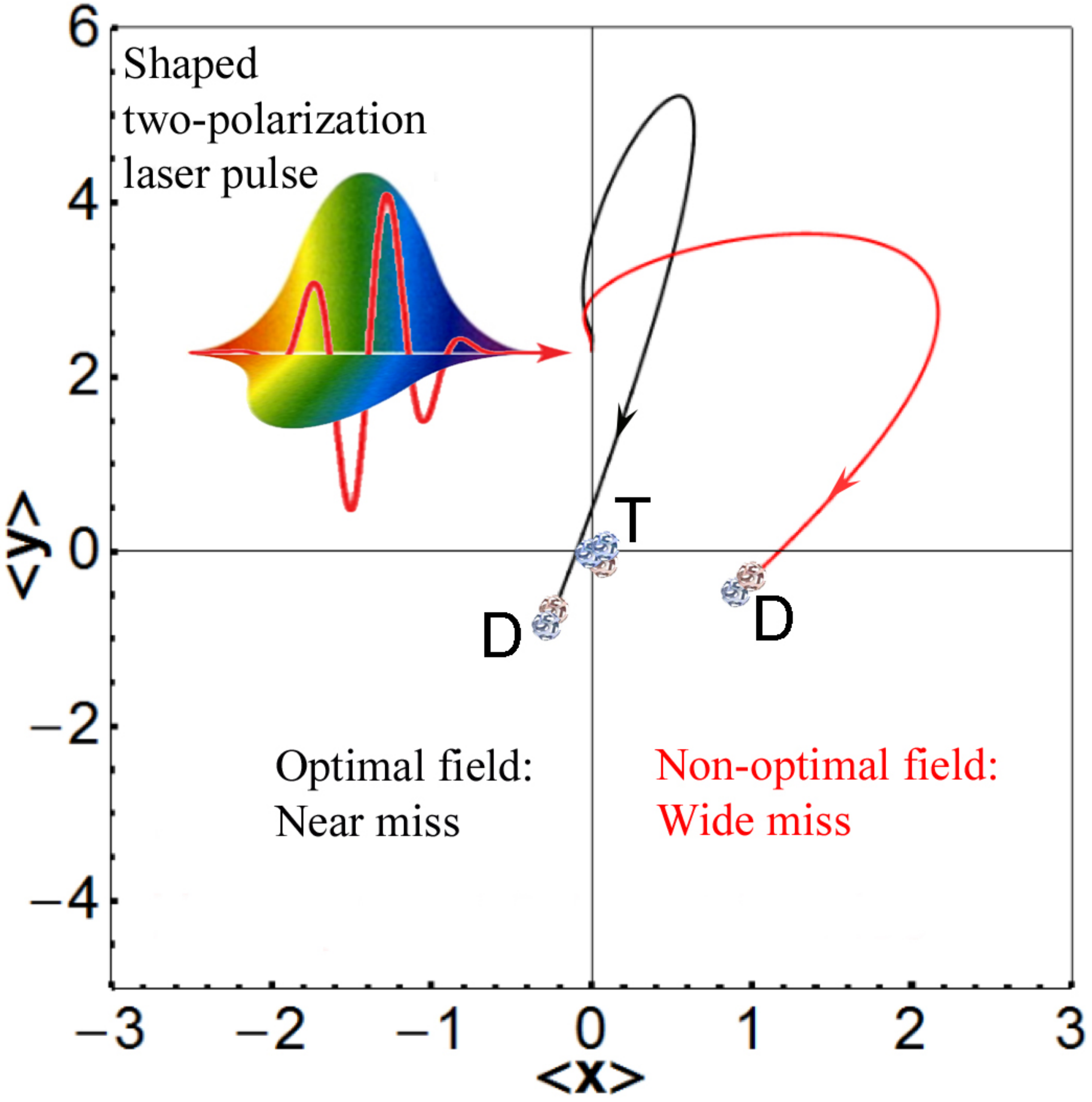

Using shaped laser pulses -- ultrashort, tuned bursts of coherent light -- might make it possible to nudge atoms in a deuterium/tritium molecule close enough to fuse, according to a new study. Researchers at Rice University, the University of Illinois at Urbana-Champaign and the University of Chile suggested that quantum-controlled fusion may provide a possible new path toward the production of energy through nuclear fusion. Credit: Gruebele Group/University of Illinois at Urbana-Champaign

Controlled nuclear fusion has been a holy grail for physicists who seek an endless supply of clean energy. Scientists at Rice University, the University of Illinois at Urbana-Champaign and the University of Chile offered a glimpse into a possible new path toward that goal.

Their report on quantum-controlled fusion puts forth the notion that rather than heating atoms to temperatures found inside the sun or smashing them in a collider, it might be possible to nudge them close enough to fuse by using shaped laser pulses: ultrashort, tuned bursts of coherent light.

Authors Peter Wolynes of Rice, Martin Gruebele of Illinois and Illinois alumnus Eduardo Berrios of Chile simulated reactions in two dimensions that, if extrapolated to three, might just produce energy efficiently from deuterium and tritium or other elements.

Their paper appears in the festschrift edition of *Chemical Physical Letters* dedicated to Ahmed Zewail, Gruebele's postdoctoral adviser and a Nobel laureate for his work on femtochemistry, in which femtosecond-long laser flashes trigger chemical reactions.

The femtochemical technique is central to the new idea that nuclei can be pushed close enough to overcome the Coulomb barrier that forces atoms of like charge to repel each other. When that is accomplished, atoms can fuse and release heat through neutron scattering. When more energy is created than it takes to sustain the reaction, sustained fusion becomes viable.

The trick is to do all this in a controlled way, and scientists have been pursuing such a trick for decades, primarily by containing hydrogen plasmas at sun-like temperatures (at the U.S. Department of Energy's National Ignition Facility and the International Thermonuclear Experimental Reactor effort in France) and in large facilities.

The new paper describes a basic proof-of-principle simulation that shows how, in two dimensions, a shaped-laser pulse would push a molecule of deuterium and tritium, its nuclei already poised at a much smaller internuclear distance than in a plasma, nearly close enough to fuse. "What prevents them from coming together is the positive charge of the nuclei, and both of these nuclei have the smallest charge, 1," Wolynes said.

He said 2-D simulations were necessary to keep the iterative computations practical, even though doing so required stripping electrons from the model molecules. "The best way to do it would be to leave the electrons on to help the process and control their motions, but that is a higher-dimensional problem that we—or someone—will tackle in the future," Wolynes said.

Without the electrons, it was still possible to bring nuclei within a small fraction of an angstrom by simulating the effects of shaped 5-femtosecond, near-infrared laser pulses, which held the nuclei together in a "field-bound" molecule.

"For decades, researchers have also investigated muon-catalyzed fusion, where the electron in the deuterium/tritium molecule is replaced by a muon," Gruebele said. "Think of it as a 208-times heavier electron. As a result, the molecular bond distance shrinks by a factor of 200, poising the nuclei even better for fusion.

"Sadly, muons don't live forever, and the increased fusion efficiency just falls short of breaking even in energy output," he said. "But when shaped vacuum ultraviolet laser pulses become as available as the near-infrared ones we simulated here, quantum control of muonic fusion may get it over the threshold."

Because the model works at the quantum level—where subatomic particles are subject to different rules and have the characteristics of both particles and waves—the Heisenberg uncertainty principle comes into play. That makes it impossible to know the precise location of particles and makes tuning the lasers a challenge, Wolynes said.

"It's clear the kind of pulses you need have to be highly sculpted and have many frequencies in them," he said. "It will probably take experimentation to figure out what the best pulse shape should be, but tritium is radioactive, so no one ever wants to put tritium in their apparatus until they're sure it's going to work."

Wolynes said he and Gruebele, whose lab studies protein folding, cell dynamics, nanostructure microscopy, fish swimming behavior and other topics, have been thinking about the possibilities for about a decade, even though nuclear fusion is more of a hobby than a profession for both. "We finally got the courage to say, 'Well, it's worth saying something about it.'

"We're not starting a company ... yet," he said. "But there may be angles here other people can think through that would lead to something practical even in the short term, such as production of short alpha particle pulses that could be useful in research applications.

"I'd be lying if I said that when we started the calculation, I didn't hope it might just solve mankind's energy problems," Wolynes said. "At this point, it doesn't. On the other hand, I think it's an interesting question that starts us on a new path."

More information: Eduardo Berrios et al, Quantum controlled fusion, *Chemical Physics Letters* (2017). DOI: 10.1016/j.cplett.2017.02.045

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