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Quantum leap at CU-NIST lab

Supercold, ultrafast techniques advance atomic physics

By Todd Neff, Camera Staff Writer
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Sammy Dallal

Adela Marian, a University of Colorado doctoral student in physics, calibrates laser light in physicist Jun Ye's JILA laboratory at CU on Wednesday.

Any good high-school chemistry student can tell you: The key to understanding atoms is knowing how their electrons behave.

Protons and neutrons provide the bulk, but it's the electrons that tell us what sorts of molecules an atom might consider joining, and in what conditions.

Using a combination of supercold and ultrafast laser techniques, a team led by Boulder researcher Jun Ye has come up with a faster and more efficient way of understanding — and influencing — electron behavior. The team's work, published Thursday in the online edition of the journal Science, promises to benefit applications as diverse as chemical analysis, chemical synthesis and quantum computing.

Ye is a research fellow with the National Institute of Standards and Technology and JILA, an institute operated jointly by the NIST and the University of Colorado. The paper is the result of a four-year effort in Ye's crowded basement lab in CU's JILA tower.

Adela Marian, a CU doctoral student in physics, began in 2000 to grind and polish what would become hundreds of mirrors and lenses now arranged across two tables in ways that would befuddle a

pinball-machine designer. When she leaves, physics doctoral student Matt Stowe will carry the torch.

Asked how equipment on two tables can function as a single system, Marian pointed upward. Mounted above was a lone mirror about the size of a quarter, which directed an invisible laser beam across the 15-foot gap to a matching mirror over the second table.

Why not just do it all on one table?

"We have some space problems," Marian said.

It all accomplishes two key things. One set of lasers isolates and drastically slows a gas of rubidium atoms. The atoms' temperature hovers just above absolute zero, at which point molecular motion

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theoretically ceases.

The second laser — the one shooting between the tables — is the engine behind a technique called laser spectroscopy. The spectroscopic laser excites the captured atoms' electrons, and detectors measure the light the electrons give off as they fall to lower quantum orbits when the laser leaves them alone again.

Both are established techniques in analyzing the properties of atoms. The JILA team broke new ground with its use of a laser that fires ultrafast — femtosecond, or quadrillionths of a second — pulses of light, each pulse packed with 100,000 different colors.

The chilled atoms' lethargy allows this laser "frequency comb" to influence and measure atomic behavior over long periods of time, exciting electrons with a wash of colors and monitoring their many reactions.

Existing techniques, in contrast, would hit atoms one frequency at a time, monitor the result, and move on sequentially to the next color — like tuning a piano one key at a time.

"This technique is like a hammer that tunes the entire piano at once," Ye said.

H. Jeff Kimble, a California Institute of Technology physicist and an authority on quantum information science, said in an e-mail that the Boulder group's work represented "a pioneering advance beyond traditional laser spectroscopy."

Leo Hollberg, a physicist and group leader in NIST's Time and Frequency Division in Boulder, said the approach would let researchers obtain detailed, precise information about atoms quickly and in parallel.

"I think that's a powerful direction for the future of atomic physics and precision instruments," Hollberg said.

Ye said his goal is to use the technique to enable the chemical synthesis of matter using "quantum control" of atoms and molecules, a feat that Hollberg said was "the holy grail of laser spectroscopy" since the 1970s.

Ye's goal is to achieve it within 10 years.

"We are no longer satisfied with knowing how matter works, but want to control the process for the benefit of mankind," Ye said.

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