Scientists propose new method to search for deviations from the Standard Model of physics

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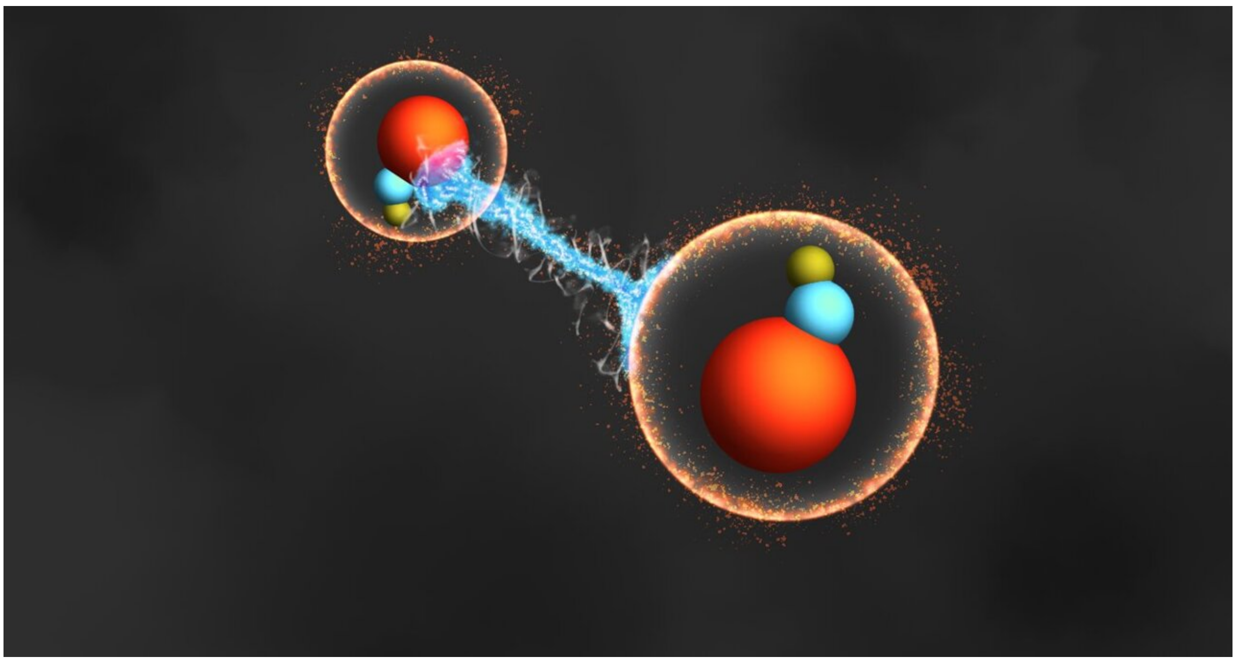

Artwork depicting entangled molecules. Credit: Caltech/Lance Hayashida

In the search for new particles and forces in nature, physicists are on the hunt for behaviors within atoms and molecules that are forbidden by the tried-and-true Standard Model of particle physics. Any deviations from this model could indicate what physicists affectionately refer to as "new physics."

Caltech assistant professor of physics Nick Hutzler and his group are in pursuit of specific kinds of deviations that would help solve the mystery of why there is so much matter in our universe. When our universe was born about 14 billion years ago, matter and its partner, antimatter, are believed to have existed in equal measure.

Typically, matter and antimatter cancel each other out, but some kind of asymmetry existed between the different types of particles to cause matter to win out over antimatter. Hutzler's group uses tabletop experiments to look for symmetry violations—the deviant particle behaviors that led to our lopsided matter-dominated universe.

Now, reporting in *Physical Review Letters*, the team, led by Chi Zhang, the David and Ellen Lee Postdoctoral Scholar Research Associate in Physics at Caltech, has figured out a way to improve their studies by using entanglement, a phenomenon in quantum physics whereby two remote particles can remain connected even without being in direct contact. The study is titled "Quantum-Enhanced Metrology for Molecular Symmetry Violation using Decoherence-Free Subspaces."

In this case, the researchers developed a new method for entangling arrays of molecules, which serve as probes for measuring the symmetry violations. By entangling the molecules, the arrays become less sensitive to background noise that can interfere with the experiment and more sensitive to the desired signal.

"It's like anchoring a bunch of rubber duckies together," Hutzler says. "If you wanted to measure the movement of the duckies across a tub, they would be less sensitive to the background noise of splashing water if you connected them altogether. And they'd be more sensitive to something you may want measure like the flow of a current since they would all respond to it collectively."

"We want to be sensitive to the structure of the molecules," Zhang says. "Uncontrolled electric and magnetic fields from the experimental setup get in the way of our measurements, but now we have a new protocol for entangling the molecules in such a way to make them less sensitive to the noise."

More specifically, this new method can be used to look for tiny tilts in electrons that may occur in response to electric fields within the molecules. "The slight rotations would indicate electrons or nuclear spins are interacting with electric fields, and that's forbidden according to the Standard Model," Hutzler says.

"Other approaches that use entanglement would typically increase sensitivity to noise," he adds. "Chi has figured out a way to reduce the noise while still giving us a sensitivity gain from entanglement."

A different recent experimental study published in *Science*, led by Hutzler and John M. Doyle of Harvard University, showed that the polyatomic molecules used in these kinds of studies have other unique abilities to shield themselves from electromagnetic noise, though without the sensitivity boost from entanglement.

In that study, the researchers showed they can tune the molecule's sensitivity to external fields and in fact make the sensitivity vanish, thereby rendering the molecules largely immune to noise.

"With the advantages of entanglement, researchers can push these experiments to probe increasingly exotic sectors of new physics," Hutzler says.

More information: Chi Zhang et al, Quantum-Enhanced Metrology for Molecular Symmetry Violation Using Decoherence-Free Subspaces, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.193602

Loïc Anderegg et al, Quantum control of trapped polyatomic molecules for eEDM searches, *Science* (2023). DOI: 10.1126/science.adg8155

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