Creating a quantum gas

1 February 2010, By Miranda Marquit

(PhysOrg.com) -- "One of the many reasons people study ultracold gases is for their potential as model quantum systems," Deborah Jin tells *PhysOrg.com*. "There is a need to model quantum many-body systems because a lot of important physics - from condensed matter and material physics to nuclear and particle physics - increasingly require an understanding of complicated quantum behavior. Ultracold gases can possible provide that through models we can interact with, helping to close the gap between what we can describe theoretically and what actually happens."

Jin is a NIST physicist and a scientist at JILA, one of the leading science research institutes in the U.S., located at the University of Colorado campus in Boulder. Jin, along with fellow NIST scientist Jun Ye and their team of researchers have prepared a molecular quantum gas in a single hyperfine state, resulting in control over the final remaining degree of freedom needed to control all aspects of molecules in an ultracold gas. The group's work has been published in Physical Review Letters*:* "Controlling the Hyperfine State of Rovibronic Ground-State Polar Molecules."

"To see quantum behavior, we want all the particles to be indistinguishable from each other," Jin explains. "All of the atoms or molecules in the gas have to be in exactly the same internal state." She says that some ultracold gases have approached this point, but the one thing lacking has been control over the hyperfine state, which accounts for nuclear spin inside the atoms that make up the molecules that form the gas.

"It seems that this degree of freedom is not worth worrying about, and in most classical physics and in chemistry, it really doesn't matter, since the amount of energy is so small. But for quantum behavior, even that should be lined up. We describe how to identify and control what's going on inside the nucleus," Jin says.

In order to create a situation allowing control over the hyperfine state, the group at JILA first used improved spectroscopy techniques to identify the state of the molecules. The state of the molecules needed to be identified, and the molecules needed to be brought to their ground state. In order to do this, the group built on techniques used for hotter samples. "It's hard to change nuclear spin, since it is weakly interacting," Jin says. "But it is easy to drive from non-rotating to rotating, and there is a weak coupling. We use a microwave field to drive rotation, and then bring the molecule back to non-rotating, but with a different nuclear spin."

"With control of this final degree of freedom, we can say that we truly do have a quantum gas," Jin insists. "If we can get the gas a little colder, we should really be able to see the quantum mechanics involved."
Before that point is reached, however, there are some steps that need to be taken. "We need a greater understanding of ultracold chemistry first, and we need to study how to 'turn on' the polar part of the molecules we use, figuring out what happen when we align them using the proper field," Jin says.

"We are making rapid progress, though," she continues. "We are quite close, closer than ever before, to being able to model interesting quantum behavior with ultracold polar molecules. And once we do that, there is a whole new world of science ahead."

More information: Ospelkaus, et. al., "Controlling the Hyperfine State of Rovibronic Ground-State Polar Molecules," *Physical Review Letters* (2010). Available online: link.aps.org/doi/10.1103/PhysRevLett.104.030402