Breaking down superfluidity

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"One of the most exciting areas of research in the last few years has been the realization of the BEC-BCS crossover," Wolfgang Ketterle tells *PhsyOrg.com*. Ketterle and a team of scientists at the MIT-Harvard Center for Ultracold Atoms have completed the first study of critical velocities in this crossover region where magnetic tuning of the interactions is possible by a Feshbach resonance.

The results are available in *Physical Review Letters*, in a piece titled "Critical Velocity for Superfluid Flow across the BEC-BCS Crossover."

In ultracold gases, the BEC-BCS crossover basically addresses how superfluidity in bosons transforms into superfluidity in fermions. At issue, says Ketterle, is how fermions can be made to interact very strongly so that superfluidity occurs at higher temperatures. Furthermore, an improved understanding of the pairing mechanism can lead to the developments of new materials that could serve as superconductors.

"Bare electrons repel each other," says Ketterle, "unless there are many other particles around them which can lead to some attraction and to pairing. Once paired, fermions act as bosons." So far, the group has studied fermionic atoms with attractive interactions, but in the future, they hope to see how to pair fermions, which repel each other, to resemble the electrons.

"These are important issues," Ketterle explains. "Superfluids and superconductors have many possible applications. We use them now, but if we understood them even better, more applications could open up." He illustrates: "Imagine having a superconducting power grid where energy flows without resistance or developing better magnets for MRIs." These are only a couple of the applications that scientists can think of now. "A better understanding of superfluids may lead to the design of new materials in the future."

But for the here and now, Ketterle's team has managed to create conditions that use tuning to control the pairing of fermions. "When we modify the external magnetic field, we can loosen up the binding between the particles until they reach a point where two of them are not bound at all, but many of them still are."

The MIT team studied the critical velocity only in the center of the atom cloud, avoiding the limitations of inhomogeneous density. They moved an optical lattice (an interference pattern between two laser beams) through the superfluid. The group found that the critical velocity is highest when molecular pairs transform into Cooper pairs "in which attractive forces are about to support a molecular state." Ketterle expects other studies to follow — and to perform additional quantitative tests of the theoretical predictions. "We have seen that this system allows us to study the breakdown of superfluidity," Ketterle says.

"The ultimate goal is to use our new tools and methods to find new regimes of superfluidity, to find out for what interactions and in what kind of geometry superfluidity is most robust," says Ketterle. "This is an exciting frontier. We are able to study superfluids over the whole range of interactions throughout the crossover. This is the latest advance toward understanding superfluidity and superconductivity."