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Number 681 #1, April 13, 2004 by Phil Schewe and Ben Stein

First Evidence for Superfluidity in an Atom-Based Fermi Gas

Evidence for superfluidity in an atom-based Fermi gas has been observed for the first time by researchers at Duke University (including John Thomas, 919-660-2508, jet@phy.duke.edu, and Michael Gehm, mgehm@ee.duke.edu, 919-403-5003). In essence, the researchers have observed an ultracold gas of lithium-6 atoms acting as one big vibrating "jelly."

While the jelly-like (or "hydrodynamic") behavior could arise in ordinary versions of ultracold lithium gases, the researchers found evidence that their gas was a superfluid, a "perfect" jelly which vibrates for a long time after being shaken.

The properties of the atomic jelly can provide information on other superfluid systems (such as [neutron stars](#)). The behavior of the jelly could even help determine whether it's physically possible to create [superconductors](#) which operate well above room temperature, which could lead to breakthroughs ranging from widely available energy-saving power lines to magnetically levitated trains. What's shared by all these systems, from a quark-gluon plasma to neutrons in neutron stars, is that they are made of strongly interacting pairs of "spin-up" and "spin-down" particles (spin up/down is analogous to the atoms having bar magnets pointing in opposite directions).

To produce the observed behavior, the researchers believe that the interaction mechanism among their lithium-6 atoms is in a weird "cross-over regime" (see [Update 671](#)), a condition in which the atom pairs are neither molecules (in which case they would form a molecular Bose Einstein condensate, see [Update 663](#)) nor they type of weakly bound Cooper pairs found in conventional superconductors.

In their experiment, the researchers cooled and trapped lithium-6 atoms with a focused laser beam, whose electric field confined the atoms. The researchers made sure the atoms were in a 50-50 mixture of spin-up and spin-down states. They then used their optical system to lower the temperature of atoms via "evaporative cooling" (i.e., allowing hotter atoms to escape to lower the overall temperature of the gas).

Next, they tested the gas's ability to act like a vibrating "jelly." To start vibrations in the gas, they turned off the trapping laser for a short time, allowing the gas to expand, and then turned the laser back on again. At this point the gas cloud was quivering, and the researchers took a series of pictures to show these vibrations (see [visuals](#)). They measured the cloud's frequency of vibration, as well as how long the vibrations persist.

In one case, they adjusted the magnetic field so that the atoms were strongly interacting. In this instance, they measured a frequency of vibration of 2837 Hz, in very close agreement with a theoretical prediction of 2830 Hz for a hydrodynamic Fermi gas. Lowering the temperature of the gas caused the vibrations or "oscillations" to last for a longer time, in contrast to an ordinary hydrodynamic gas, in which a lower temperature would cause the oscillations to "damp" or die out more quickly.

The Duke physicists ruled out two non-superfluid scenarios for the behavior, namely that the oscillations were caused by (1) a high rate of atomic collisions (however, in this scenario, the oscillations would die out more quickly as the temperature is lowered) and (2) a collisionless gas that

oscillates via mean-field interactions, the net effect of many atom-to-atom interactions (however, the predicted vibration frequency for this scenario differs by 500 Hz from the observations).

Still, the researchers do not have an iron-clad case for superfluidity yet, in large part because the theory for strongly interacting superfluid Fermi gases is incomplete. Namely, there is no prediction of how the damping times of the vibrations should increase with decreasing temperature, which would help to identify a "transition temperature" below which superfluidity would occur. (In their setup, the Duke team started seeing evidence for superfluidity at temperatures below 0.4 to 0.7 Microkelvin.)

In summary, the experiments constitute first evidence for what could plausibly be superfluid behavior based on pairs of fermion atoms in a gas. The photos provide macroscopic information (i.e., viewing the overall gas that's visible to the naked eye) that complement the "microscopic" information provided by other groups ([Update 671](#)), which probe the pairing of spin-up and spin-down atoms. ([Kinast et al.](#), *Physical Review Letters*, 16 April 2004.)

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