Using silicon chips to trap ultra-cold atoms

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The long-term goal of Professor J. H. Thywissen's physics lab at the University of Toronto is to be able to tailor a system with a Hamiltonian which simulates a high temperature superconductor.

"The idea," Seth Aubin, a post-doctoral researcher in the group, tells *PhysOrg.com* "is to create your own Hamiltonian for the simulation." The research at the University of Toronto, published May 28th in *Nature Physics*, simplifies and accelerates the efficient production of the ultra-cold fermion gases required for the quantum simulations of high temperature superconductors.

"The idea of using a silicon chip is novel," says Aubin. "It's neat that we're using these chips with lithographically printed wires. The wires can be used to get tighter traps. It's the tightness that is important." Aubin explains that tighter traps allow for a higher rate of collision between particles, as well as a higher re-thermalization rate. And this is important when one is dealing with trapping rare atoms for use in a simulation.

The University of Toronto team, which includes Aubin and his professor Thywissen, along with S. Myrskog, M. H. T. Extavour, L. J. LeBlanc, D. McKay and A. Stummer, has created a more effective way to generate ultra-cold Fermi gas with the use of the tighter traps and an apparatus that is both more efficient and more compact: "Before," explains Aubin, "one uses two connected vacuum chambers. We only use one. A typical time scale for the cycle is between 30 seconds and a minute and a half. We can do it in less than 30 seconds." The tough part, he says, is evaporative, sympathetic cooling. Along with his collaborators, Aubin has demonstrated how to cut that part of the cycle down to six seconds.

Using the tight magnetic trap, microfabricated on a silicon chip, Aubin and his colleagues can perform species-specific evaporative and sympathetic cooling on the trapped atoms. When the process is complete, the fermions can then be loaded into an optical lattice. The fermions represent the electrons in a Hamiltonian, and the optical lattice simulates a crystal lattice. Using the device, arrangements could be made in order to solve various Hamiltonians using the simulation.

Aubin admits that while this particular system is usually faster, some non-magnetic traps have accomplished parts of the cycle more rapidly. “However,” he says, “those traps are better-suited for large numbers of atoms. We are working with rarer atoms. The other schemes are less efficient when it comes to using rare atoms.”

While there are no immediate applications for the work, Aubin sees a promising future, about 10 years down the road, for physics devices as a result of the work with Fermi degenerate states on chips. Because multiple traps (on the micro level) could be loaded onto a single chip, it would be possible to create quantum systems that interact. This could be a boon for quantum information processing, more precise measuring apparatuses and interferometry. “Fermion interferometers,” explains Aubin, “are expected to provide significant improvement in measurement of both inertial and gravitational forces.” He also touts the usefulness of fermions in atomic clocks, making them more accurate.

“Fermions are more accurate than bosons,” Aubin explains. “Degenerate boson gases or Bose-Einstein condensates turn out to be very precise but not very accurate. While a fermion would lose a little in precision—hardly anything at all, though—it would gain enormously on the accuracy.”

Using this new ultra-cold fermion production technique will also simplify the study of dual species quantum gases, many-body atomic states, and emerging forms of superfluidity.

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