Delving into the world of the ultra-cold

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(PhysOrg.com) -- In Swinburne University's 'cold molecules lab', where temperatures one millionth of a degree above absolute zero are routinely achieved, researchers are making significant advances in understanding the weird and wonderful world of quantum mechanics.

While this field of physics - and its key players, bosons and fermions - might be difficult for most to comprehend, the Swinburne researchers hope that their studies could lead to new understandings of mysterious processes like high temperature superconductivity.

A superconductor is a fermionic superfluid, in which particles - in this case electrons - form pairs that can move around with zero resistance. Superfluidity and superconductivity are dramatic examples of quantum behaviours on a macroscopic scale that could one day have significant implications for everyday technologies.

The Swinburne researchers' latest findings have been published in the journal Physical Review Letters.

According to physicist and group leader Dr Chris Vale the work has greatly improved the researchers' understanding of the fundamental laws underpinning superfluidity.

"When you cool a gas down to the extreme temperatures found in Swinburne's lab, the laws of quantum mechanics take over and atoms in the gas start behaving in strange ways - acting more like waves than particles," he said.

"Quantum behaviours in large systems lead to a range of phenomena such as magnetism, superfluidity and superconductivity. But we still lack a complete theoretical understanding of how some materials, like high temperature superconductors, really work."

"In our latest study we looked specifically at how strongly interacting fermions can pair up in ultra-cold environments, which is an essential precursor to forming a superfluid."

Fermionic particles, such as protons, neutrons and electrons, are the building blocks of all matter, and the way they combine determines the physical properties of any substance.

Two years ago it was discovered theoretically that fermions in these strongly interacting quantum systems should pair up in a universal manner, meaning that the same law applies to all types of fermions whose interactions can be categorised in the same way.

The Swinburne researchers are the first group in the world to be able to test this universal law in a lab and prove its validity.

According to Vale, knowing how fermions pair up forms a piece in the puzzle that will help researchers understand some of the mysteries behind quantum mechanics. In particular, researchers have a long term vision of using this knowledge to emulate some of the exotic quantum behaviours, such as high temperature superconductivity.

"In normal circumstances when you run a current through a metal it heats up. Even though metal is a conductor, it still has a small resistance to electrical current, which leads to losses and energy being dissipated as heat.

"However when you cool some materials down to extremely low temperatures, they display superconductivity, where the electrical resistance goes all the way down to zero. This allows for a flow of current with no energy loss at all - 100 per cent efficiency."

According to Dr Vale, a complete understanding of high temperature superconductivity may eventually enable researchers to engineer new materials that display the phenomenon at increasingly high temperatures.

"If we could obtain the knowledge required to produce materials which superconduct close to room temperature, this would have a dramatic impact on everyday technologies.

"For example power transmission cables could transfer electricity over long distances with zero loss."

Such dreams are still a long way off according to Vale. "But every time we learn something new about the fundamental processes at play in these fermionic superfluids, we take one step closer to making this goal a reality."

Provided by Swinburne University of Technology

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