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Super-accurate atomic clock doubles up as quantum sim

19:00 08 August 2013 by **Lisa Grossman**
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The most accurate timekeepers in the world just got a new use. It turns out they can double up as simulators to help us better understand the deepest mysteries of the quantum world.

Many problems in physics are difficult to untangle because their underlying behaviour, governed by the intricate rules of quantum mechanics, is too complex for computers to simulate.

One example is the mysterious phenomenon of high-temperature superconductivity, in which electrons move around with no resistance inside a material. This is probably thanks to the collective quantum behaviour of hundreds of particles, too many to simulate computationally. Another example is magnetism, the result of quantum interactions between electrons .

Electrons' behaviour inside solids can be physically modelled using networks of atoms cooled to trillionths of a degree above absolute zero. These are bigger and easier to control than electrons themselves, so are ideal for experiments that yield new insights. "Recently there is a big push for using ultracool atoms to mimic solid-state materials," says Ana Maria Rey of JILA, a lab jointly run by the US National Institute of Standards and Technology and the University of Colorado in Boulder.

Clocks to the rescue

However, there is a major hurdle to overcome: the fact that ultra-low temperatures are hard to produce in the lab. "This has been a very important limitation," says Rey. Now, she and her colleagues have stumbled upon a way to mimic quantum behaviour in a system several orders of magnitude warmer: an atomic clock.

Atomic clocks are the most accurate clocks we have and their behaviour is used in the modern definition of the second. They keep time by tracking the hyper-regular movements of a group of atoms between two energy levels.

Rey's team worked with an atomic clock based on an ensemble of strontium atoms trapped by a series of lasers. When a laser pumps in energy, the atoms oscillate between their ground state and an excited state with incredible regularity, acting as the "tick" of the clock.

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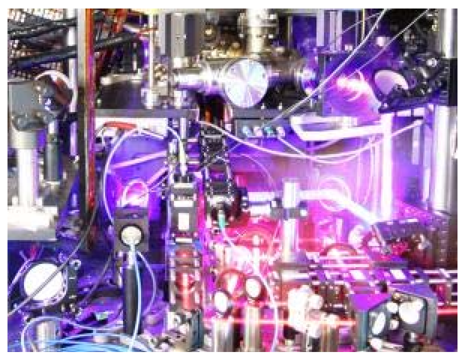

Is the ultimate timepiece now also the ultimate electron simulator? *(Image: Ye group and Brad Baxley, JILA)*

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To improve the strength of the clock's signal, Rey's team tried upping the number of atoms. Unfortunately, this reduced the clock's accuracy because the atoms' mutual interactions sometimes changed the clocklike regularity of the energy transitions. However, it also suggested a new use for the clock. "The fact that the frequency is changing with the number of atoms is very bad," Rey says. "But it's also a tool."

Secrets of spin

Mathematically speaking, the atoms were behaving a lot like electrons in magnetic materials. Electrons all have a property called spin, which can be visualised as an arrow pointing up or down. In a magnet, all the spins point in the same direction, thanks to quantum interactions between them that are still poorly understood.

Rey says that the strontium atoms in the ground state can be used to simulate spin-down electrons, and the excited atoms, spin-up electrons. Tracking the emergence and details of the interactions between the atoms could then shed light on the nature of the quantum interactions between electrons in magnets.

Crucially, unlike the network of atoms normally used to simulate electron behaviour, atomic clocks work at the relatively balmy temperatures of millionths of a degree above absolute zero.

"These are fascinating results," says Mikhail Lukin of Harvard University, who was not involved in the new study. "This work can result in fundamental new insights into quantum dynamics of spin systems."

It's also good for the atomic clock, he adds: knowing how the atoms interact should help us build ever more accurate timekeepers.

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