Energizer atoms: Physicists find new way to keep atoms excited

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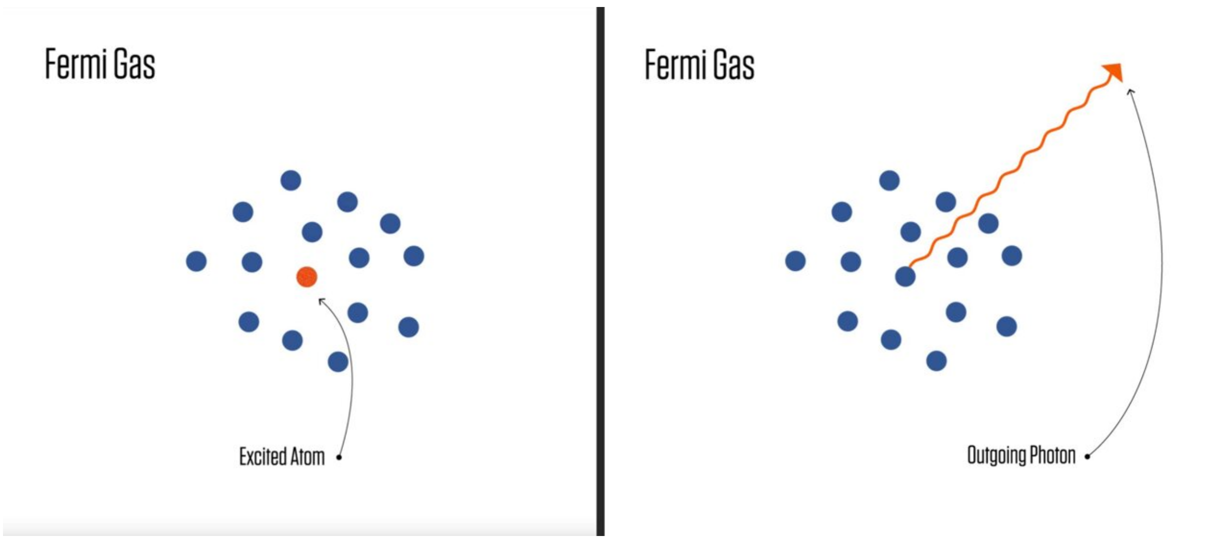

Still images from animation of JILA's experiment keeping atoms excited longer than usual. Credit: Hanacek/NIST

JILA researchers have tricked nature by tuning a dense quantum gas of atoms to make a congested "Fermi sea," thus keeping atoms in a high-energy state, or excited, for about 10% longer than usual by delaying their normal return to the lowest-energy state. The technique might be used to improve quantum communication networks and atomic clocks.

Quantum systems such as atoms that are excited above their resting state naturally calm down, or decay, by releasing light in quantized portions called photons. This common process is evident in the glow of fireflies and emission from LEDs. The rate of decay can be engineered by modifying the environment or the internal properties of the atoms. Previous research has modified the electromagnetic environment; the new work focuses on the atoms.

The new JILA method relies on a rule of the quantum world known as the Pauli exclusion principle, which says identical fermions (a category of particles) can't share the same quantum states at the same time. Therefore, if enough fermions are in a crowd—creating a Fermi sea—an excited fermion might not be able to fling out a photon as usual, because it would need to then recoil. That recoil could land it in the same quantum state of motion as one of its neighbors, which is forbidden due to a mechanism called Pauli blocking.

The blocking achievement is described in the Nov. 19 issue of *Science.* JILA is jointly operated by the National Institute of Standards and Technology (NIST) and University of Colorado Boulder.

"Pauli blocking uses well-organized quantum motional states of a Fermi sea to block the recoil of an atom that wants to decay, thus prohibiting spontaneous decay," NIST/JILA Fellow Jun Ye said. "It is a profound quantum effect for the control of matter's properties that was previously deemed unchangeable."

The idea of engineering an atom's excited-state lifetime by embedding it in a Fermi sea has been proposed before, but the JILA group is the first, along with other research described in the same issue of *Science*, to actually do it. This is the first time that atoms' internal radiation properties have been linked to their external motion.

The JILA team carried out the experiments with a low-energy, or degenerate, Fermi gas of thousands of strontium atoms. The JILA group uses these quantum gases to make the latest atomic clocks. In these low-temperature Fermi gases, all the atoms' properties are restricted to specific values, or quantized, and the atoms avoid each other by keeping a minimum distance between pairs. By contrast, atoms in ordinary gases are randomly distributed, and they do not collectively influence each other.

The researchers used blue light to excite atoms in the Fermi sea and then measured the resulting photon radiation along different directions. By setting up specific conditions, the team reduced photon emission along a narrow scattering angle by up to 50%. In this case, an atom prepared in the excited state would on average remain in this state 10% longer than usual. The natural excited lifetime of five nanoseconds was too short to measure, so the researchers used photon scattering as an indirect indicator. Future experiments using different energy levels in the atoms or denser and even colder gases could extend excited states for longer time periods or even block decay entirely, Ye said.

Key features of the experiment included making a gas with the lowest possible energy, enabling the purely quantum-mechanical blocking phenomenon to occur. In addition, the Fermi sea was large enough that atoms in the middle couldn't escape. Atoms on the surface can't be blocked as easily.

Finally, the researchers excited only a small number of atoms and collected the emitted photons at a narrow angle with respect to the blue excitation beam. This configuration enabled observation of small motion transfers. A large angle would give the atoms too much of a momentum kick, increasing their chances of escape and weakening the blocking effect.

The JILA technique offers new ways to quantum-engineer atom-light systems, with potential applications such as protecting optical qubits in quantum communication networks and improving atomic clock stability by extending atom interrogation times to maintain exact ticking.

More information: Christian Sanner et al, Pauli blocking of atom-light scattering, *Science* (2021). DOI: 10.1126/science.abh3483. www.science.org/doi/10.1126/science.abh3483

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