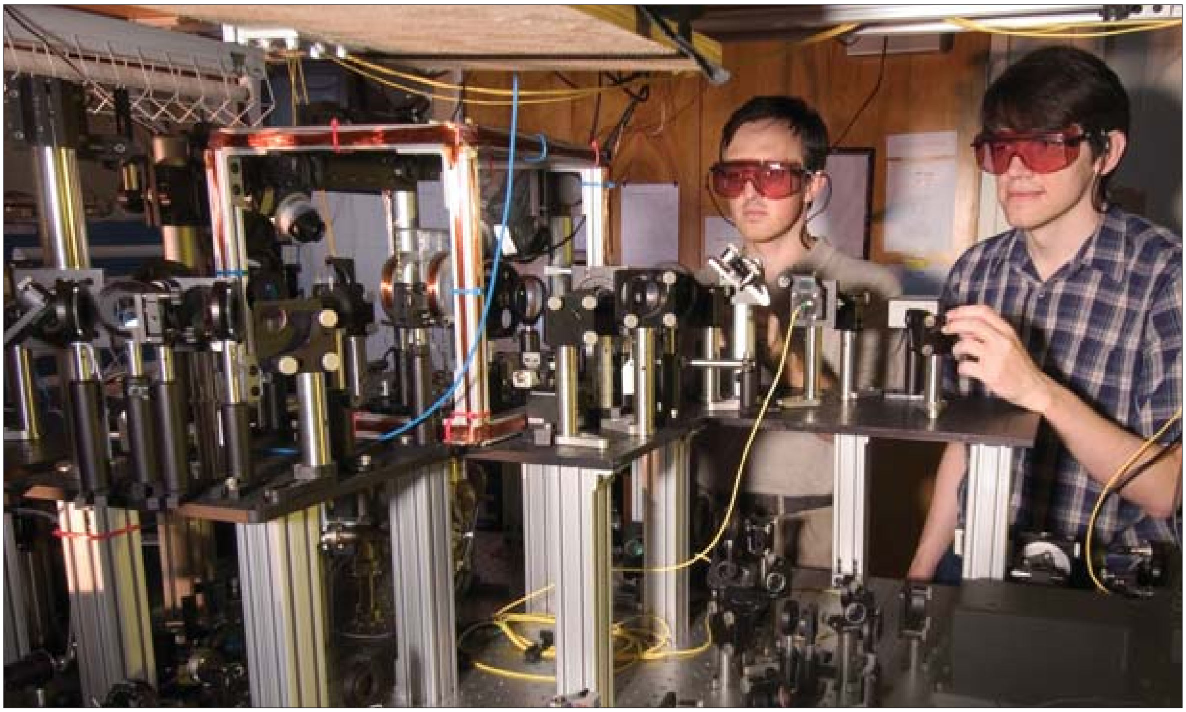
Scatterings

Stephanie Dean



Courtesy Georgia Institute of Technology

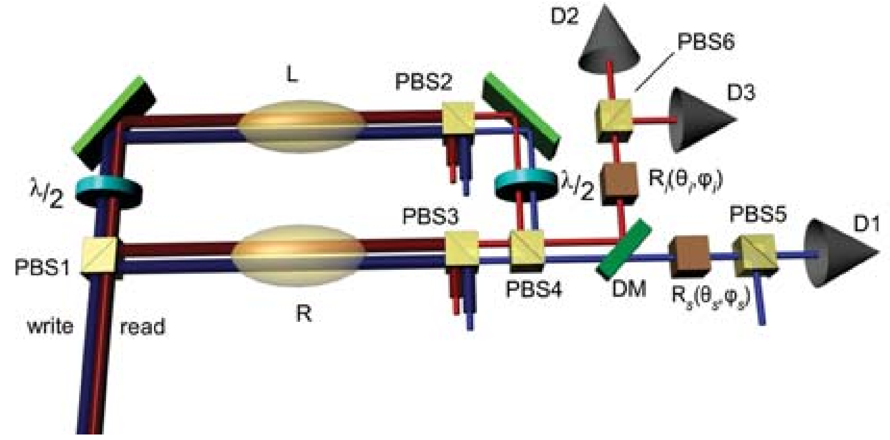
Georgia Tech physicists Alex Kuzmich (*left*) and Dzmitry Matsukevich operate the optical set-up used to achieve matter-to-light quantum state transfer.

Converting Quantum Information From Matter into Light

Alex Kuzmich and Dzmitry Matsukevich of the Georgia Institute of Technology have successfully converted quantum information from matter into light, opening the door for the "parallel processing of information by a quantum computer, providing a massive speed-up of computations," according to Kuzmich. Ian A. Walmsley, Ph.D., a physicist at Oxford University, says that Kuzmich and Matsukevich's findings represent a real advance in the field and demonstrate a significant step in developing quantum memories. "The ability to map quantum information from an easily transportable system (i.e., a light field) to an easily stored and localized one (i.e., atoms) represents an important and unique achievement," he says.

Although practical applications of turning quantum states of matter into light could be 7 to 10 years away, Kuzmich explains that "distributed quantum networks could be created, consisting of several local quantum processors (containing atomic quantum bits) interconnected by optical fibers to transport single photons," with the benefit of "allowing the whole network, which may be spread over many distant places, to act as a single quantum computer, or as a device to share information among several parties in a secure way."

Kuzmich and Matsukevich began their experiment by creating an optically thick cloud of about one billion rubidium atoms. Kuzmich explains that rubidium was used because "it is a good atom for laser cooling and trapping." This allowed them to have a cold, dense cloud of rubidium, which was essential for the experiment. The thicker an atomic cloud is, the better the interaction of the atoms with a single photon. "It was this coherent enhancement of



PBS1-6, polarizing beam splitters, λ/2, half waveplate, polarization state transformers, $R_s(\theta_s,\phi_s)$ and $R_i(\theta_i,\phi_i)$, (D1,D2,D3), single photon detectors, DM, dichroic mirror.

light-atom interaction strength due to the many atoms that allowed us to convert a single atomic quantum bit into a photonic one," says Kuzmich.

Next, the researchers defined two smaller clouds within the larger one (each consisting of about 100,000 atoms) for their atomic quantum bit, or "qubit." The clouds existed in a "single collective excitation" state, both acting together, meaning that there were many atoms involved in forming the single qubit.To define the clouds, Kuzmich and Matsukevich used a polarized beam splitter to create two beams of light. They passed the beams through the rubidium cloud to select the atoms involved in the qubit. The beams "induced spontaneous Raman scattering of a signal photon with slightly shorter wavelength," Kuzmich explains. The emission of the photon was accompanied by a transition of one atom to a different level (single spin excitation of the two clouds). It was experimentally impossible to distinguish which atom emitted the photon and made the transition. The photon was entangled with the atomic qubit.

Within the quantum bit there were two basis states, L and R. These states correspond to the zeros and ones in traditional computer bits, with the significant difference being that in quantum states the two levels can exist "simultaneously" and act essentially as *both* zeros and ones.

After the detector registered the photon, the atomic ensemble was "prepared in any desired state, thereby concluding the preparation of the memory qubit," according to Kuzmich. Next, Matsukevich and Kuzmich passed a 795-nanometer "read" laser pulse through the memory qubit, resulting in a single idler photon with the state of the atomic quantum memory encoded onto it. After culling out the extraneous "classical" light, the quantum signal photon was transmitted by the dichroic mirror, passed through an arbitrary polarization state transformer and a polarizer, and directed onto a single-photon detector, thereby successfully transferring quantum information from matter into light.

According to Dr. Michael Chapman of the Georgia Institute of Technology, "essentially all future advances in quantum communication and distributed quantum computation will require basic matter-light quantum state transfer. Matsukevich and Kuzmich's result is an important step toward quantum computing." Chapman's group has recently achieved coherent interaction of samples of cold, optically trapped rubidium atoms with ultra-high finesse cavities. Combining their approaches, Chapman and Kuzmich are hoping to develop a highly efficient quantum node that should allow implementation of a diverse array of goals in quantum information science.

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