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At Last! Light Brought to a Halt

For the first time, physicists in two separate laboratories have effectively brought a light pulse to a stop. In the process, physicists have accomplished another first: the non-destructive and reversible conversion of the information carried by light into a coherent atomic form. Sending a light pulse into specially prepared rubidium (Rb) vapor, a group at the Harvard-Smithsonian Center for Astrophysics led by Ron Walsworth (617-495-7274) and Mikhail Lukin (617-496-7611) has (1) slowed the pulse's "group velocity" to zero and (2) stored its information in the form of an atomic "spin wave," a collective excitation in the Rb atoms. (A spin wave can be visualized as a collective pattern in the orientation of the atoms, which spin like tops and hence act like tiny bar magnets. "Spin" is merely the name for the tiny magnetic vector in each of the atoms.) The atomic spin wave is coherent and long-lived, which enables the researchers to store the light pulse's information and then convert it back into a light pulse with the same properties as the original pulse.

This new accomplishment in a simple system increases the promise for quantum communication, which may someday be used to connect potentially ultrafast quantum computers in a large network analogous to the Internet. Usually photons (the quanta of light) are absorbed by atoms, destroying the information carried by the light. With the present method, in principle, no information in the light pulse is lost. Previous efforts to slow light (such as Hau et al., *Nature*, 18 February 1999) have reduced the signal speed to about 1 mph (Update 472) by using a process called electromagnetically induced transparency (EIT; see Updates 37, 344 and Stephen Harris's article in *Physics Today*, July 1997).

Walsworth, Lukin and colleagues have gone the rest of the way to a zero light-pulse speed by using a novel technique which was recently proposed theoretically (Lukin, Yelin and Fleischhauer, *Phys. Rev. Lett.* 1 May 2000; Fleischhauer and Lukin, *Phys. Rev. Lett*. 29 May 2000). The light storage experiment begins with the Harvard-Smithsonian scientists shining a "control" laser beam into a glass cell filled with rubidium vapor (about 70-90 degrees Celsius), which puts the atoms into a conventional EIT state in which they cannot absorb light in the traditional sense. The scientists then send in a "signal" pulse of light which contains the information they want to store. As the pulse enters the rubidium cell its propagation speed is reduced to about 2,000 mph. Since the front edge of the signal pulse enters the cell (and hence is decelerated) first, the pulse experiences dramatic spatial compression: from several kilometers in free-space to a few centimeters inside the rubidium vapor. The light in the vapor cell interacts with the atoms (see figure at Physics News Graphics), changing the atoms' spin states coherently and creating a joint atom-photon system known as a polariton. (For a nice descriptions of polaritons see Phys Rev Focus, 26 April 2000.

The light-atom interaction causes the polaritons to act as if they have an effective mass; so one way to understand the signal pulse's reduced speed is that the mixture with atoms, in the form of a polariton, effectively weighs down the otherwise massless photons. Next, the Harvard-Smithsonian scientists stop the signal pulse of light by gradually turning off the control beam, which causes more atoms to be mixed with fewer photons, thereby increasing the polariton mass and further reducing the signal pulse's speed. When the control beam is completely off the polariton is purely atomic, the light pulse is effectively halted, and no signal pulse emerges from the glass cell during the storage period. At this point there are no photons remaining in the cell. The light does not go into warming of the atoms, as is the usual case. Instead the photons are expended in the creation of the atomic spin wave. Thus, the information that the light pulse carried (all that one can know about the photons) is stored in the atomic spin wave, waiting to be released as a light pulse that is in principle identical to the incident pulse.

An alternative way to understand the slowing of light is to think of the signal pulse as a wave made of many different components, each with a
different frequency. The Rb atoms bend or "refract" the individual components of the light by different amounts depending on each component's frequency. The vapor cell's frequency-dependent index of refraction causes the component waves to add together in such a way that the group velocity, the velocity of the composite pulse, slows appreciably. The dimming of the control beam makes the vapor's index of refraction more sharply dependent on frequency, and this serves to reduce the group velocity further. The dimming causes the atoms to become transparent to a narrower range of frequencies. But simultaneously, the light wave (or more precisely, the combination of light wave and atomic spin wave) is continually slowing down, maintaining its shape but narrowing its range of component frequencies so that the atoms are still unable to absorb it. After a relatively long delay the control beam can be turned back on, reverting the polariton to being a light wave by coaxing the atoms to emit the exact signal light pulse that entered the medium.

In brief: (1) the length of a light pulse is compressed from kilometers to centimeters in a properly-prepared rubidium vapor; (2) the information carried by the light pulse is then imprinted upon the ensemble of rubidium atoms in the form of long-lived spin waves; and (3) the light pulse can later be read out on demand. This new light storage method is robust because information is maintained in collective atomic spin states, which are much less sensitive to dissipation, losses, and quantum-computer-crashing decoherence effects than are excited electronic states in atoms.

Scientists believe that the light storage method is quite general and that the simplicity of its implementation is a big advantage. They even speculate that the technique may be utilized in certain solid-state materials. The Harvard-Smithsonian demonstration experiment is exciting news for scientists worried about preserving the coherence of quantum information transfer. With further work, this technique should allow for the storage and transmission of photon quantum states useful for quantum communication and computation. (Phillips et al., *Physical Review Letters*, 29 January 2001.)

Walsworth and Lukin say that a very similar result has been recently obtained by Lene Hau's group (Harvard/Rowland Institute of Science) in an ultra-cold atomic gas. In addition, an upcoming theory paper (Kocharavskaya et al., *Phys Rev. Lett.*, 22 January) discusses a novel technique for making a light beam not only stop in its tracks but reverse its direction; this effect could be useful for non-linear optics applications.

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