Light Changed to Matter

{mosloadposition top}Light Changed to Matter, Then Stopped and Moved CAMBRIDGE, Mass., Feb. 8, 2007 -- By converting light into matter and then back again, physicists have for the first time stopped a light pulse and then restarted it a small distance away. This "quantum mechanical magic trick" provides unprecedented control over light and could have applications in fiber-optic communication and quantum information processing.   Harvard University professor Lene Hau explains how she stops light in one place then retrieves and speeds it up in a completely separate place. (Photo: Justin Ide/Harvard News Office) In quantum networks, information optically transmitted over the network is converted into matter, processed, and then converted back into light. The physicists at Harvard University hope that their discovery could provide a possible way to do this, since matter, unlike light, can easily be manipulated. Their findings were published this week in the journal Nature.

"We demonstrate that we can stop a light pulse in a supercooled sodium cloud, store the data contained within it, and totally extinguish it, only to reincarnate the pulse in another cloud two-tenths of a millimeter away," said Lene Vestergaard Hau, Mallinckrodt Professor of Physics and of Applied Physics in Harvard's Faculty of Arts and Sciences and School of Engineering and Applied Sciences.

In a "quantum mechanical magic trick" devised by Harvard University physicists, a light pulse is extinguished in one ultracold atom cloud (purple), converted to matter and then revived in another before being allowed to exit the second cloud in its original state. (Image courtesy of Sean R. Garner) This marks another milestone for Hau in light manipulation. In 1998, she slowed light, which travels in free space at a speed of 186,000 miles a second, to just 38 miles per hour in a cloud of ultracold atoms. Einstein and others have theorized that the speed of light in free space can't be changed. Two years later, she stopped light completely in a similar cloud, then restarted it without changing its characteristics. She received a $500,000 MacArthur Foundation Fellowship (so-called "genius grant") for these experiments.

In her latest work, Hau and her co-authors, Naomi S. Ginsberg and Sean R. Garner, found that the light pulse can be revived, and its information transferred between the two clouds of sodium atoms, by converting the original optical pulse into a traveling matter wave which is an exact matter copy of the original pulse, traveling at a molasses-like pace of 200 m (600 ft) per hour. The matter pulse is readily converted back into light when it enters the second of the supercooled clouds -- known as Bose-Einstein condensates -- and is illuminated with a control laser.

"The Bose-Einstein condensates are very important to this work because within these clouds atoms become phase-locked, losing their individuality and independence," Hau said. "The lock-step nature of atoms in a Bose-Einstein condensate makes it possible for the information in the initial light pulse to be replicated exactly within the second cloud of sodium atoms, where the atoms collaborate to revive the light pulse."

Within a Bose-Einstein condensate -- a cloud of sodium atoms cooled to just billionths of a degree above absolute zero -- a light pulse is compressed by a factor of 50 million, without losing any of the information stored within it. The light drives some of the cloud's roughly 1.8 million sodium atoms to enter into "quantum superposition" states, with a lower-energy component that stays put and a higher-energy component that travels between the two clouds.   Diagram showing the time line for the Harvard research. (Image courtesy of Naomi S. Ginsberg, Sean R. Garner and Lena V. Hau) The amplitude and phase of the light pulse stopped and extinguished in the first cloud are imprinted in this traveling component and transferred to the second cloud, where the recaptured information can recreate the original light pulse.

The period of time when the light pulse becomes matter, and the matter pulse is isolated in space between the condensate clouds, could offer scientists and engineers a tantalizing new window for controlling and manipulating optical information; researchers cannot now readily control optical information during its journey, except to amplify the signal to avoid fading. The new work by Hau and her colleagues marks the first successful manipulation of coherent optical information.

"This work could provide a missing link in the control of optical information," Hau said. "While the matter is traveling between the two Bose-Einstein condensates, we can trap it, potentially for minutes, and reshape it -- change it -- in whatever way we want. This novel form of quantum control could also have applications in the developing fields of quantum information processing and quantum cryptography."

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