black holes have a kind of entropy, or information content, and emit radiation. But Hawking's result posed two puzzles. The form for the entropy suggested that all the black hole's information was concentrated at its event horizon, rather than spread throughout its volume, as it is in ordinary objects. Moreover, black-hole radiation raised worrisome questions about information loss.

The radiation, said Hawking, stems from the pairs of virtual particles that, according to quantum mechanics, continually wink in and out of existence throughout space. Just outside the event horizon, the black hole's enormous gravity might convert one of these normally fleeting events into a single particle that flies off into space, leading to the radiation—and an effective mass loss for the black hole. Thus, the black hole shrinks, and its information content dwindles. But the laws of quantum mechanics imply that information is never destroyed, only dispersed or rearranged, so Hawking's picture could be viewed as a paradox.

Last year, Andrew Strominger of the University of California, Santa Barbara, and Vafa tested the theory by constructing black holes from scratch out of D-branes. They compactified massive, charged D-branes by wrapping them around 6D tori to create small, massive objects resembling black holes. The team then considered possible excitations of the D-branes—"ripples" along the compactified dimensions—which could encode information about the black hole's internal state. By counting up the number of possible vibrations for a given black hole, they found an entropy that agreed exactly with the value Hawking and others had calculated.

But they also found, says Vafa, that the information existed not just on the event horizon, but "hidden in those extra [six] dimensions." At Penn, Cvetič and Finn Larsen went further. Building on earlier work Cvetič did with Donam Youm of the Institute for Advanced Study, Larsen reported, they showed how the entropy is sometimes split between the usual horizon and a cloaked, "inner" horizon that forms a second point of no return: Light rays that pass inside it cannot even return to the outer horizon. "Our calculations would say that at least mathematically, the inner horizon plays at least as big a role as the outer horizon," explains Larsen.

Later work by Vafa and Strominger even suggested a way out of the information paradox Hawking had posed. Their D-brane–based analysis showed that the "hidden" information might not be lost as the black hole shrinks: It might be escaping along with the Hawking radiation. If string theory can plug a cosmic information leak, it may start getting more attention on Earth.

–James Glanz

OPTICS

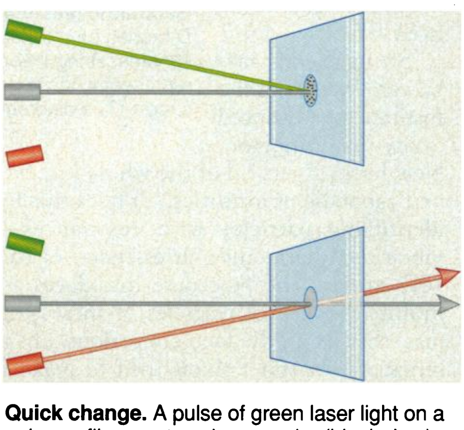
Tripping the Light at Fantastic Speeds

In today's world of high-speed telecommunications, researchers are always on the lookout for faster ways to send information. The speediest schemes today encode data as pulses of laser light fired through glass optical fibers. But the comparatively slow electronic switches that pulse the light on and off limit the overall speed of these systems. Now researchers at the University of Utah in Salt Lake City and Osaka University in Japan have come up with a new polymer-based optical switch that has the potential to dramatically boost the data rate.

Beams of laser light trip and reset this speedy switch. One laser fills the polymer with evanescent charge pairs called excitons, which block an information-carrying infrared beam; a second laser can collapse the pairs and open the switch again in just a trillionth of a second. "It's something I find very interesting," says Joseph Perry, a chemist at the Jet Propulsion Laboratory and the California Institute of Technology, both in Pasadena, who has worked on designing other polymers for high-speed switching applications. Perry and others caution, however, that a series of technical hurdles—such as the polymer's tendency to break down when hit repeatedly with laser light—must be overcome before the new switches are ready for the market.

Present-day optical switches apply an electric field to an inorganic crystal to change its optical properties, turning light on and off. Such devices can generate light pulses at about 20 gigahertz, or 20 billion times per second. In recent years, Perry and others have been working to design polymers that can boost the switching speed of the same basic setup to more than 100 gigahertz. But because of the hair-trigger response of excitons, the new polymer switch has the potential to switch 10 times faster still, at 1 terahertz, or a trillion times a second.

The new switch relies on polymers that can conduct electricity and emit light, derivatives of a compound known as poly (p-phenylene vinylene), or PPV. Several research teams recently used these materials to make the first polymer-based laser, which absorbs laser light of one color and reemits it as a beam of a different color (*Science*, 27 September 1996, p. 1800). In their new work, which they report in the 2 June *Physical Review Letters*, Utah physicists Sergey Frolov and Valy Z. Vardeny and their colleagues exploit these light-handling talents to create their switch. Other high-speed exciton-based switches have been reported in the past, but they rely on different optical effects for their switching.



Quick change. A pulse of green laser light on a polymer film creates charge pairs (black dots), which block an infrared, data-carrying beam (taupe). Red laser light collapses the pairs, allowing the beam to pass through the film.

To make the conducting polymer opaque and turn the switch "off," the researchers hit it with a pulse of green laser light. The pulse excites electrons in the material to a higher energy state, leaving behind positively charged electron vacancies, or "holes." These newly created energetic electrons and holes stick close together to form excitons, which themselves absorb light at an infrared wavelength. The absorption essentially blocks the infrared data beam.

To turn the switch back "on" again, the researchers zap the polymer with a pulse from a red laser that is precisely tuned to stimulate the excitons' electrons and holes into recombining. That makes the polymer transparent again to the infrared data beam. In their initial demonstration, Vardeny and company only created 80 million pulses per second. Raising this to a trillion would of course also require the control lasers triggering the switches to be pulsing at the same speed. Conventional setups can accomplish that by splicing together separate, rapid-fire laser pulse trains, although such systems are difficult to set up.

For this and other reasons, even Vardeny admits that the scheme has a long way to go before it could become a real-world technology. One "particularly difficult" problem, says electrical engineer Mohammed Islam of the University of Michigan, Ann Arbor, is that conducting polymers tend to break apart quickly when triggered to give off photons of light. Another obstacle, he adds, is that the polymer films heat up when they absorb infrared light, which may cause further degradation. But if researchers can work out these problems, telecommunications could be in for a big switch.

–Robert F. Service