

A tiny switch for a few particles of light

April 29 2016





A mediator between particles of light: An organic molecule mediates the



interaction between a control and a probe beam, which are indicated by the magenta or the green spheres in the foreground. Here the energy of the two light beams changes when they leave the molecule. This is represented symbolically by the yellow and the blue sphere in this illustration. Credit: © Ella Maru Studio

The Jedi knights of the Star Wars saga are engaged in an impossible fight. This does not result from the superiority of the enemy empire, but from physics because laser swords cannot be used for fighting like metallic blades: beams of light don't feel each other. Until now, for a light beam to perceive another one, it has required a large chunk of material as intermediary, and very intense light. A team at the Max Planck Institute for the Science of Light has demonstrated for the first time a mediation process with only a single organic molecule and just a handful of photons. The researchers influence and switch another light beam with these particles of light. This basic experiment not only promises a place in physics textbooks, but it may also help in the development of nano-optical transistors for a photonic computer.

Currently, the future of the computer industry is unclear. Semiconductor components like the transistor cannot be miniaturized indefinitely and run at ever-higher speeds. One possibility for developing more compact and powerful computers could result from processing information with photons instead of electrons. That is a major objective of photonics. However, there is a fundamental problem in the attempt to develop a purely optical transistor: "Light cannot simply be switched by other light in the way that electric current is switched with current in a conventional transistor", explains Vahid Sandoghdar, Director of the Nano-optics Division at the Max Planck Institute for the Science of Light and Alexander von Humboldt Professor of the Friedrich-Alexander University, Erlangen-Nürnberg. How shy particles of light are becomes obvious when one crosses the beams of two torches or two lasers. What



happens is: nothing. "A medium is required to mediate the light-light interaction"

A control beam alters the optical properties of the molecule

Now Vahid Sandoghar's team has succeeded in controlling light with a single organic molecule and just a handful of photons. To this effect, the researchers first cooled <u>molecules</u> which they had embedded in a solid matrix to minus 272 degrees Celsius. With the help of modern microscopy and spectroscopy techniques, they made two carefully focussed <u>laser beams</u> overlap on a single molecule: a so-called control beam and a probe beam, which should be switched. "The control beam has the task of changing the optical properties of the molecule so that it becomes transparent for the second one, the probe beam", explains Andreas Maser, who performed the experiments as part of his doctoral thesis.





Light switches light: Molecules (red spheres) are embedded in a molecule and intensely cooled. Then a weak control beam (yellow) which is focussed through a lens is enough to manipulate a probe beam (pink). The transmission of the probe beam depends on the colour difference between the two beams. Credit: © MPI for the Science of Light

Previously, powerful laser beams and macroscopic materials were needed to switch light with light, as this process relies on an interaction which physicists call non-linear. In such non-linear interactions the optical properties of a material also depend on the light intensity and not just on the intrinsic material. In addition, non-linear interactions are much weaker than the normal linear interaction. This results from the reduced ability of the electrons in the molecule to follow the electric field vibrations of the light waves at different frequencies.

Just a single photon should be able to switch the molecule

Now, the Erlangen-based researchers were able to switch the probe beam with just a few light particles, as they conducted their experiment at a temperature close to absolute zero. "At very low temperatures the interaction cross-section of the molecule becomes a multiple of its geometrical size", explains Benjamin Gmeiner, who also played a key role in the experiments. So the molecule becomes something like an illusionary giant, with the result that almost every photon of the control beam can interact with the molecule. "Therefore, just a few photons from the laser beam are enough to alter the <u>optical properties</u> of the molecule." The researchers are even convinced that the control pulse can be weakened still further. "In principle, a single photon should be enough



to alter the fate of a second photon", says Vahid Sandoghdar.

The researchers will now continue to work on controlling a <u>light</u> signal with individual photons. Simultaneously, the team in Erlangen is focussing rather on the practical side of things: the researchers would like to embed the molecule as a nano-optical transistor in a photonic wave-guide structure that should serve to wire up many molecules as is common in electrical circuitry. This would be an important step towards the future perspective of processing information in a photonic computer.

More information: Andreas Maser et al. Few-photon coherent nonlinear optics with a single molecule, *Nature Photonics* (2016). DOI: 10.1038/nphoton.2016.63

Provided by Max Planck Society

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