MAX PLANCK INSTITUTE
OF QUANTUM OPTICS

Garching, 13.05.2010 Press Release

Optical quantum transistor using single atoms

Physicists at MPQ control the optical properties of a single atom!

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Due to the continued miniaturization of computer chip components, we are about to cross a fundamental boundary where technology can no longer rely on the laws of the macroscopic world. With this in mind, scientists all over the world are researching technologies based on quantum effects that can be used to communicate and process information. One of the most promising developments in this direction are quantum networks in which single photons communicate the information between different nodes, e.g. single atoms. There the information can be stored and processed. A key element in these systems is Electromagnetically Induced Transparency (EIT), an effect that allows to radically change the optical properties of an atomic medium by means of light. Previously, scientists have studied this effect and its amazing properties, using atomic ensembles with hundreds of thousands of atoms. Now, scientists in the group of Prof. Gerhard Rempe, Director at the Max Planck Institute of Quantum Optics (MPQ) in Garching and Head of the Quantum Dynamics Division, have managed to control the optical response of a single atom using laser light (Nature, Advanced Online Publication, DOI: 10.1038 /nature09093 May 2010). While representing a corner stone in the development of new quantum based technologies, these results are also fundamental for the understanding of how the quantum behaviour of single atoms can be controlled with light.

Electromagnetically Induced Transparency (EIT) describes the effect, that the interaction of an atomic medium with a weak laser field can be controlled and manipulated coherently with a second, strong laser field. Practically, this is achieved by irradiating the medium with two laser beams: the action of a strong control laser causes the medium to become transparent for a weak probe laser. The properties derived from EIT allow the storing and retrieval of information between an atomic sample and light pulses, thus providing a powerful interface between photonic information and stationary atoms.

In all experiments performed so far, the medium was made of a very large number of atoms. In contrast, in the experiment described here only a single Rubidium atom is addressed. The atom is trapped inside a high-finesse optical cavity in order to amplify the atom-light interaction such that atom and cavity form a strongly coupled system. Then the transmission of laser light – the probe laser – incident on the cavity axis is measured. When there is no atom inside the cavity, the laser light is transmitted. On the other hand, the presence of the atom causes the light to be reflected, and the transmission drops (see Fig. 1a). With an additional control laser of very high intensity applied transverse to the cavity axis, the single-atom EIT condition is achieved and maximum transmission is recovered (See Fig. 1b). The single atom effectively acts as a *quantum optical transistor*, coherently controlling the transmission of light through the cavity.

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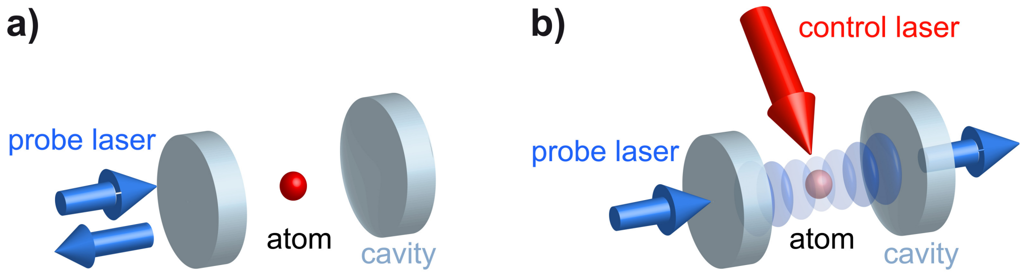

Optical transistor using a quantum of matter.
(a) *The presence of the atom results in light reflection ("off" action of the transistor)*
(b) *Using single atom EIT, the atom becomes transparent and full transmission is recovered ("on" action of the transistor).*

In addition, the team of Prof. Rempe succeeded in performing EIT experiments when more atoms were added inside the cavity, one by one in a very controlled way. "Using EIT with a controlled number of atoms provides the possibility to manipulate many quantum properties of light fields transmitted by the cavity", says Martin Mücke, who works on this experiment as a doctoral student. "Usually photons don't interact with each other. With this scheme we may be able to achieve a long sought goal: strong interaction between photons, mediated by a single atom. Such a set-up is a potential building block for a working quantum computer."
Olivia Meyer-Streng

Original publication:

Electromagnetically induced transparency with single atoms in a cavity
M. Mücke, E. Figueroa, J. Bochmann, C. Hahn, K. Murr, S. Ritter, C. J. Villas-Boas and G. Rempe.
Nature, Advance Online Publication, DOI: 10.1038/nature09093, May 2010

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