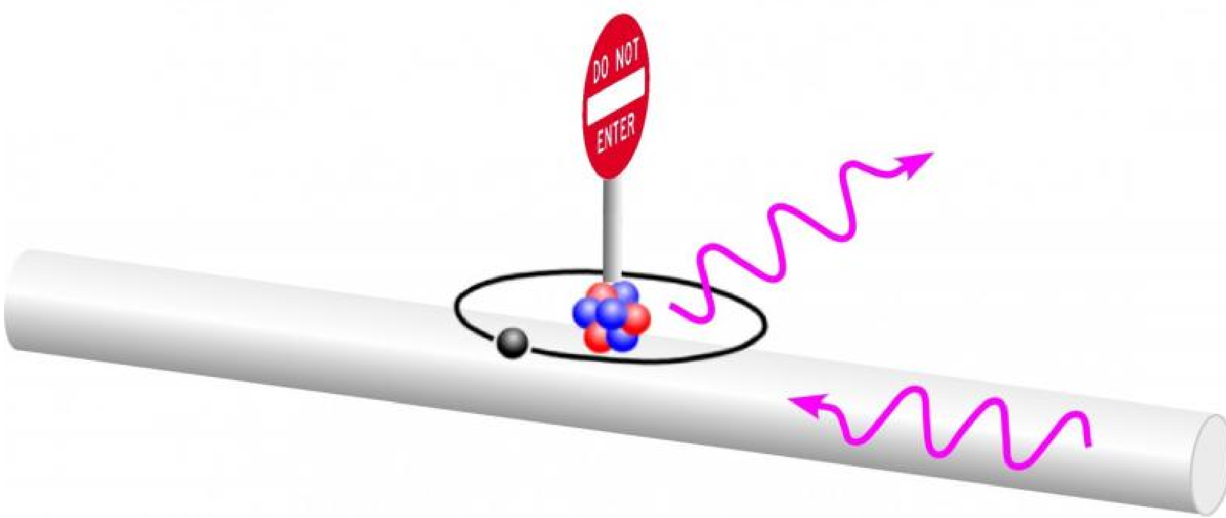
Nanoscale one-way street for light

December 14 2015



An optical device at nanoscale which allows light to pass in only one direction has been developed at TU Wien (Vienna). It consists of alkali atoms which are coupled to ultrathin glass fibres.

If light is able to propagate from left to right, the opposite direction is usually allowed as well. A beam of light can normally be sent back to its point of origin, just by reflecting it on a mirror. Researchers at TU Wien have developed a new device for breaking this rule. Just like in an electrical diode, which allows current to pass only in one direction, this glass fibre-based device transmits light only in one direction. The one-way-rule holds even if the pulse of light that passes through the fibre consists of only a few photons. Such a one-way-street for light can now be used for optical chips and may thus become important for optical signal processing.

Optical Signal Processing Instead of Electronics

Elements which allow light to pass in only one direction are called "optical isolators". "In principle, such components have been around for a long time", says Arno Rauschenbeutel, from the Vienna Center for Quantum Science and Technology at the Atominstitut at TU Wien. "Most optical isolators, however, are based on the Faraday effect: A strong magnetic field is applied to a transparent material between two crossed polarization filters. The direction of the magnetic field then determines the direction in which light is allowed to pass."

For technical reasons, devices using the Faraday effect cannot be constructed at the nanoscale – an unfortunate fact, because this would have many interesting applications. "Today, researchers seek to build optical integrated circuits, similar to their electronic counterparts", says Rauschenbeutel. Other methods for breaking this symmetry only work at very high intensities. But in nanotechnology, an ultimate goal is to work with extremely faint light signals, which may even consist of individual photons.

Glass Fibres and Atoms

Arno Rauschenbeutel's team chose a completely different approach: Alkali atoms were coupled to the light field of an ultrathin glass fibre. In a glass fibre, the light can propagate forwards or backwards. There is, however, another property of light which has to be taken into account: the direction of oscillation of the light wave, also called the polarization.

The interaction of light and the glass fibre modifies the oscillation state of the light. "The polarization rotates, much like a helicopter's rotor", says Arno Rauschenbeutel. The sense of rotation depends on whether the light travels forwards or backwards. In one case, the light wave oscillates clockwise and in the other, counterclockwise. The direction of propagation and the state of oscillation of the light wave are locked to each other.

If the alkali atoms are prepared in the right quantum state and coupled to the light in the ultrathin glass fibre, it is possible to make them react differently to the two senses of light rotation. "The light in the forward direction is not affected by the atoms. However, light which travels backwards and consequently rotates the other way around, couples to the alkali atoms and is scattered out of the glass fibre", says Arno Rauschenbeutel.

The Atomic State as a Quantum Switch

This effect has been demonstrated in two different ways at TU Wien: In the first approach, about 30 atoms were placed along the glass fibre. Upon sending in light, a high transmission of almost 80% was measured for one propagation direction while it was ten times less in the other direction. In the second approach, only a single rubidium atom was used. In this case, the light was temporarily stored in an optical microresonator, so that it could interact with the atom for a relatively long time. This way, similar control over the transmission could be achieved.

"When we only use one single atom, we have a much more subtle control over the process", says Rauschenbeutel. "One can prepare the atom in a quantum superposition of the two possible states, so that it blocks the light and lets it pass at the same time." According to classical physics, this would be impossible, but quantum physics allows such combinations. This would open the door to new, exciting possibilities for optical processing of quantum information.

More information: Clément Sayrin et al. Nanophotonic Optical Isolator Controlled by the Internal State of Cold Atoms, *Physical Review X* (2015). DOI: 10.1103/PhysRevX.5.041036

Provided by Vienna University of Technology