Nanoparticles break the symmetry of light

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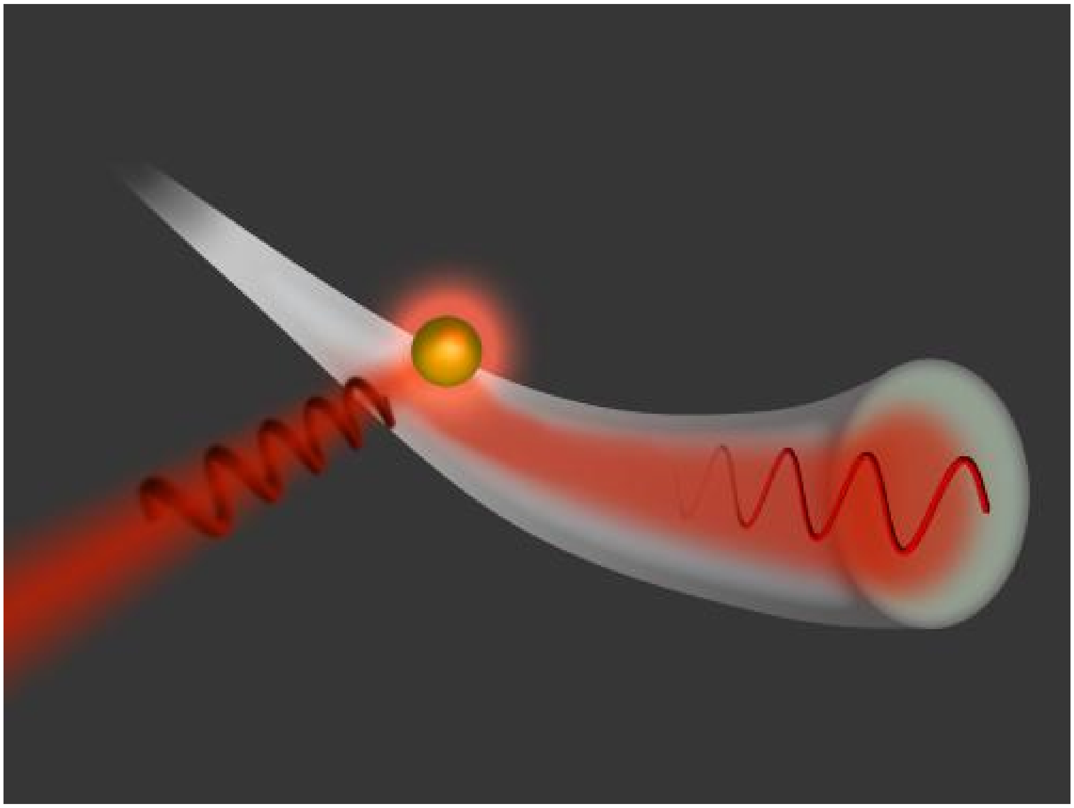

Light hits a gold particle, which then emits light into a glass fibre - into only one direction.

How can a beam of light tell the difference between left and right? At the Vienna University of Technology (TU Wien) tiny particles have been coupled to a glass fibre. The particles emit light into the fibre in such a way that it does not travel in both directions, as one would expect. Instead, the light can be directed either to the left or to the right. This has become possible by employing a remarkable physical effect – the spin-orbit coupling of light. This new kind of optical switch has the potential to revolutionize nanophotonics.

The researchers have now published their work in the journal *Science*.

Gold Nanoparticles on Glass Fibres

When a particle absorbs and emits light, this light is not just emitted into one direction. "A particle in free space will always emit as much light into one particular direction as it emits into the opposite direction", says Professor Arno Rauschenbeutel (TU Wien). His team has now succeeded in breaking this symmetry of emission using gold nanoparticles coupled to ultra-thin glass fibres. The incident laser light determines whether the light emitted by the particle travels left or right in the glass fibre.

Bicycles and Airplane Propellers

This is only possible because light has an intrinsic angular momentum, the spin. Similar to a pendulum which can swing in one particular plane or move in circles, a light wave can have different directions of oscillation. If it has a well-defined vibrational direction, it is called a "polarized wave". "A simple plane wave has the same polarization everywhere", says Arno Rauschenbeutel, "but when the intensity of the light changes locally, the polarization changes too."

Usually, the light oscillates in a plane perpendicular to its direction of propagation. If the oscillation is circular, this is similar to the motion of an airplane propeller. Its rotational axis – corresponding to the spin – points into the direction of propagation. But light moving through ultra-thin glass fibres has very special properties. Its intensity is very high inside the glass fibre, but it rapidly decreases outside the fibre. "This leads to an additional field component in the direction of the glass fibre", says Arno Rauschenbeutel. The rotational plane of the light wave pivots by 90 degrees. "Then, the direction of propagation is perpendicular to the spin, just like a bicycle, moving into a direction which is perpendicular to the axes of the wheels."

By checking the wheels' direction of rotation – clockwise or counter-clockwise – we can tell whether a bicycle moves right or left when looking at it from the side. It is exactly the same with the beams of light in the ultra-thin glass fibre. The sense of rotation of the light field is coupled to the direction of motion. This kind of coupling is a direct consequence of the glass fibre geometry and the laws of electrodynamics. The effect is called "spin-orbit-coupling of light".

Coupling Rotation and the Direction of Motion

When a particle that is coupled to the glass fibre is irradiated with a laser in such a way that it emits light of a particular sense of rotation, the emitted light will thus propagate into just one particular direction inside the glass fibre – either to the left or to the right. This effect has now been demonstrated using a single gold nanoparticle on a glass fibre. The fibre is 250 times thinner than a human hair; the diameter of the gold particle is even four times less. Both the diameter of the fibre and the particle are even smaller than the wavelength of the emitted light.

"This new technology should be easily made available in commercial applications. Already now, the whole experiment fits into a shoebox", says Arno Rauschenbeutel. "The method could be applied to integrated optical circuits. Such systems may one day replace the electronic circuits we are using today."

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