A 'pause button' for light particles

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How do you stop something that is faster than anything else, intangible and always in motion by nature? A team led by physicists Dr. Thorsten Peters and Professor Thomas Halfmann is doing the seemingly impossible: stopping light for tiny fractions of a second. They then end the stopover at the push of a button letting the light pulse continue its journey. The researchers are even stopping individual light particles.

What sounds like a physical gimmick could be of use for future applications. So-called quantum technology attempts to use bizarre effects of quantum physics for faster computers, more precise sensors and bug-proof communications. Photons, which are used in quantum technology as information carriers, play a decisive role in this.

To this end, physicists, for example, require light sources that emit individual photons at the push of a button. To process the information stored on light particles, it would also be important for individual photons to interact, which they do not usually do. In future quantum computers, photons will for example have to transfer their information to atoms and vice versa. To this end too, the interaction between the two types of particles must be intensified, which the photons stopped by the group from the TU Darmstadt could make possible.

How does this emergency stop for light work? For some time now it has been possible to freeze photons and re-emit them on command. However, whilst they are stopped, the photons do not exist as such. They are swallowed by an atomic cloud, which then assumes a so-called excited state and stores the photon as information. Only upon receipt of a signal does the excitation change back into a photon, which then continues on. The researchers in Darmstadt are doing it in a similar manner, but with one crucial difference: their photons are actually preserved.

The light literally stands still. The team uses a special glass fiber with a hollow channel in the center with a diameter of less than ten thousandths of a millimeter. The fiber has a porous structure round the core that keeps light at bay. This causes a laser beam to concentrate in the center of the hollow channel. Its cross-section narrows to around one thousandth of a millimeter. The researchers use the light beam as a kind of trap for atoms. They introduce atoms of rubidium into the hollow fiber, which concentrate in the center of the laser beam due to electromagnetic forces. The researchers then send the photons they want to stop into the channel. Roughly speaking, the photon is brought to a complete stop by two additional laser beams that are guided into the hollow fiber on both sides. Metaphorically speaking, these hold the photons between them like two footballers kicking the ball back and forth.

"It is also similar to a chamber in which light is thrown back and forth between two mirrors," as Thorsten Peters explains. "Just without a mirror." The TU-team is the first to succeed in slowing down photons in such a narrow capillary in this way and it was not easy. It is made extremely complicated by an optical property known as birefringence. The team was able to refine their method through a laborious birefringence analysis to the point where stopping individual photons became possible.

But simply stopping light itself they did not satisfy themselves. "Our objective," says Peters, "was to make photons interact with atoms more strongly than they normally do." In particular, it should be possible for two light particles to interact with an atom at the same time, which would produce a useful phenomenon known in physics as nonlinear optics in which photons penetrate a medium, such as a special crystal. When two photons simultaneously strike one of the atoms in the crystal, they interact with one another, which changes the frequency, i.e., the color, of the light. The new frequency could, for example, be the sum of the frequencies of the photons that are sent in.

There are many technical applications for such effects, for example in laser pointers. The method does have one disadvantage: high intensity lasers are needed to guarantee that enough pairs of photons strike an atom within the medium simultaneously. "With our method, on the other hand," says Peters, "a weak light intensity may be sufficient." This is possible because the atoms are confined to the same narrow area as the laser beam within the hollow fiber, thus maximizing the contact between the light and the atomic cloud. Therefore the probability of two photons hitting an atom simultaneously is relatively high even when the light intensity is low. So the same technical trick that makes it possible to stop the photons should also create a new method for nonlinear optics.

The Darmstadt-based team has more ideas for how to apply his new process. One of these involves a switchable source for single photons. Another is to create a crystal made of photons. Crystals usually consist of atoms arranged in an absolutely regular grid, comparable to layered spheres. A large number of stopped photons could also form an ordered grid. "We could use this to simulate a solid," says Peters. The physics of solid materials is an active field of research. Theoretical models are used in research to gain a better understanding of them—often through computer simulations. But the models are so complex that they quickly overwhelm the computers. Researchers are therefore looking for other ways to imitate crystals. A simulated solid made of photons would be one way of doing this.

"We are continuing to work intensively on this," says Peters. According to the physicist, collaboration with other research groups is crucial for success. The team achieved the current work in collaboration with groups from Taiwan and Bulgaria within the framework of an EU-funded project. Industrial partners are also involved in the research project, whose objective is to develop innovative technologies for the interaction of light with matter. "The exchange is very active," Peters is pleased to say. The next successes will not be long in coming.

More information: Thorsten Peters et al, Single-photon-level narrowband memory in a hollow-core photonic bandgap fiber, *Optics Express* (2020). DOI: 10.1364/OE.383999

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