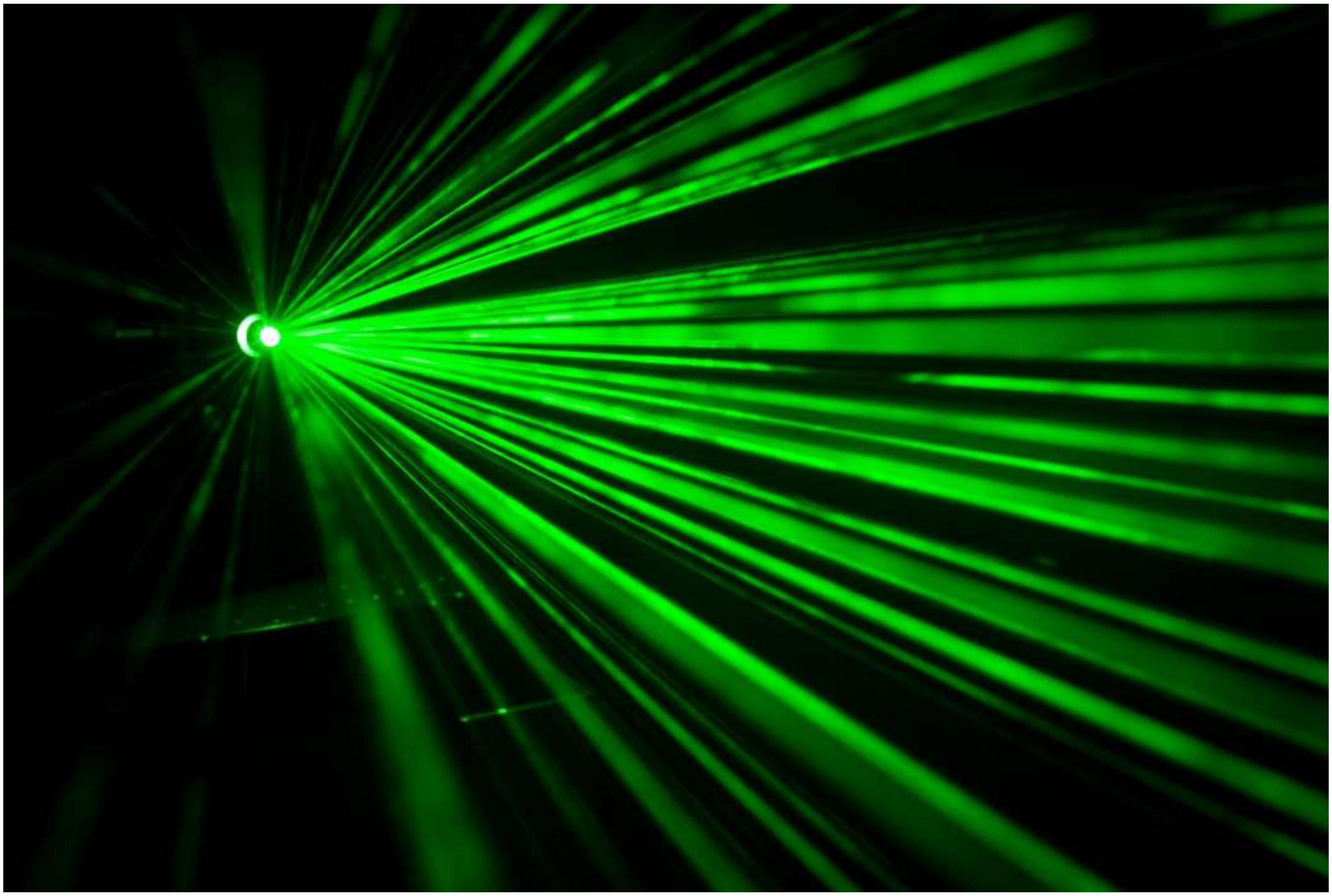
Physicists discover new state of light using ‘super-photons’

By Zack Fishman
April 1, 2021



Light can enter different states, too. (Pixabay/Ralf Vetterle)

Using photons fused with quantum effects into an extreme form of matter, German physicists generated and detected a new state of light, expanding scientists' understanding of how light behaves and opening a path for further investigation into other strange forms allowed by quantum mechanics.

Researchers from the University of Bonn, in Germany, whose paper will be published April 2 in *Science*, said the findings will aid in their search for more new states of light and might someday see application in sending quantum-encrypted messages.

Like other forms of matter and energy in the universe, light can exhibit behaviors of both a wave and a particle in different scenarios, according to the rules of quantum mechanics. Its particle is the photon, a packet of the smallest amount of light possible that make radiation, which includes the spectrum from radio waves to visible light and gamma rays.

Light can be manipulated into different states similar to water's phases of ice, liquid and vapor. Some of its states include laser light and thermal light, which is emitted by a lamp or other source and is based on its temperature.

In a 2010 study, some of the same authors took photons at very low temperatures and melded them into a unified quantum material called a Bose-Einstein condensate. This "super-photon" was essentially a single wave rather than the several once-distinct photons.

"It's when particles march in lockstep," said Martin Weitz, a professor of physics at the University of Bonn and the lead author and co-senior author of the most recent study. "It's like a big wave that oscillates, not small individual waves of the individual particles."

It was the first time a Bose-Einstein condensate was made out of photons, though the state of matter has been achieved before with atoms of elements such as rubidium and lithium.

In the recently published study, the physicists were able to modify the super-photon into a new state, which they described as a "biexponential" or overdamped phase. Overdamped systems reduce in strength over time; they are present in a car's shock absorbers, which prevent the energy created by hitting a bump in the road from reverberating, or "oscillating," through the vehicle.

The overdamped phase of light emitted photons in a similar pattern during the scientists' experiment. They first created a Bose-Einstein condensate between two curved mirrors only one-thousandth of a millimeter apart, with a liquid dye filling the space. Photons injected by a laser continually bounced between the mirrors and repeatedly passed through a liquid dye present in the space, which cooled the photons to room temperature and allowed for the super-photon's creation.

But as the set of mirrors leaked photons and new ones were added by the laser, the super-photon system was put out of equilibrium and no longer had an exactly defined temperature, causing the amount of leaked photons to oscillate between large and small amounts — in other words, the light got brighter and dimmer, which was measured by the research team. But when the number of photons was low enough, the super-photon transitioned into the new phase, and the brightness of the leaked light stopped oscillating and simply decayed, in an overdamped fashion, more toward a constant output.

The 2010 study revealed that light's change between laser light and a super-photon is continuous, meaning the light can take on any combination of the two states. This differs from, for instance, the phases of water; ice and water can be physically mixed, but there is no intermediate phase between the solid and the liquid phases.

But according to the recent findings, there is a sharp transition between either of these states and the new overdamped phase, making it clear that the new state is different from the other two.

According to Weitz, the new state of light could someday be applied in a communication method between several parties that encrypts the messages using the effects of quantum mechanics. Quantum key distribution, as the method is known, sends information by connecting users with quantum entanglement and detects eavesdropping, but current approaches are slow at connecting more than two groups.

The overdamping phase of photons could be used to improve a multiparty quantum key distribution, the physicist said, though real-world applications are still "far down the road."

"With this technique, the hope is that one can produce entangled states with many partners fast enough that it becomes interesting for such quantum key distribution," Weitz said.

He and his colleagues wrote in the paper that their experimental methods could be used to explore phases of quantum systems other than light. They also plan to investigate other states of light by coupling multiple sets of overdamped photons into a single system.

The study, "Observation of a non-Hermitian phase transition in an optical quantum gas," published April 2 in Science, was authored by Fahri Emre Öztürk, Tim Lappe, Göran Hellmann, Julian Schmitt, Jan Klaers, Frank Vewinger, Johann Kroha and Martin Weitz, University of Bonn.

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