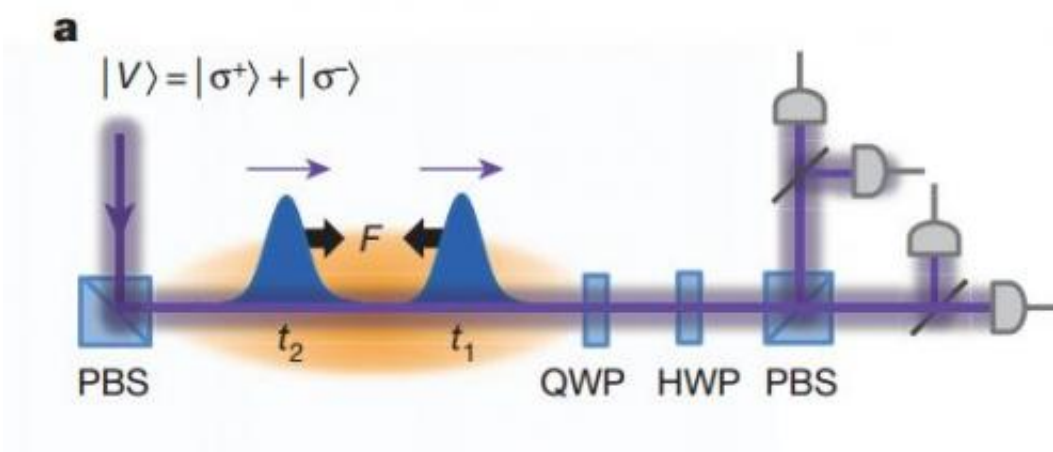


Scientists create never-before-seen form of matter

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| Photons with strong mutual attraction in a quantum nonlinear medium. Credit: *Nature*.

Harvard and MIT scientists are challenging the conventional wisdom about light, and they didn't need to go to a galaxy far, far away to do it.

Working with colleagues at the Harvard-MIT Center for Ultracold Atoms, a group led by Harvard Professor of Physics Mikhail Lukin and MIT Professor of Physics Vladan Vuletic have managed to coax [photons](#) into binding together to form molecules – a [state of matter](#) that, until recently, had been purely theoretical. The work is described in a September 25 paper in *Nature*.

The discovery, Lukin said, runs contrary to decades of accepted wisdom about the nature of light. Photons have long been described as [massless particles](#) which don't interact with each other – shine two [laser beams](#) at each other, he said, and they simply pass through one another.

"Photonic molecules," however, behave less like traditional lasers and more like something you might find in [science fiction](#) – the light saber.

"Most of the properties of light we know about originate from the fact that photons are massless, and that they do not interact with each other," Lukin said. "What we have done is create a special type of medium in which photons interact with each other so strongly that they begin to act as though they have mass, and they bind together to form molecules. This type of photonic bound state has been discussed theoretically for quite a while, but until now it hadn't been observed.

"It's not an in-apt analogy to compare this to light sabers," Lukin added. "When these photons interact with each other, they're pushing against and deflect each other. The physics of what's happening in these molecules is similar to what we see in the movies."

To get the normally-massless photons to bind to each other, Lukin and colleagues, including Harvard post-doctoral fellow Ofer Fisterberg, former Harvard doctoral student Alexey Gorshkov and MIT graduate students Thibault Peyronel and Qiu Liang couldn't rely on something like the Force – they instead turned to a set of more extreme conditions.

Researchers began by pumped rubidium atoms into a vacuum chamber, then used lasers to cool the cloud of atoms to just a few degrees above absolute zero. Using extremely weak [laser](#) pulses, they then fired single photons into the cloud of atoms.

As the photons enter the cloud of cold atoms, Lukin said, its energy

excites atoms along its path, causing the photon to slow dramatically. As the photon moves through the cloud, that energy is handed off from atom to atom, and eventually exits the cloud with the photon.

"When the photon exits the medium, its identity is preserved," Lukin said. "It's the same effect we see with refraction of light in a water glass. The light enters the water, it hands off part of its energy to the medium, and inside it exists as light and matter coupled together, but when it exits, it's still light. The process that takes place is the same it's just a bit more extreme – the light is slowed considerably, and a lot more energy is given away than during refraction."

When Lukin and colleagues fired two photons into the cloud, they were surprised to see them exit together, as a single molecule.

The reason they form the never-before-seen molecules?

An effect called a Rydberg blockade, Lukin said, which states that when an atom is excited, nearby atoms cannot be excited to the same degree. In practice, the effect means that as two photons enter the atomic cloud, the first excites an atom, but must move forward before the second photon can excite nearby atoms.

The result, he said, is that the two photons push and pull each other through the cloud as their energy is handed off from one atom to the next.

"It's a photonic interaction that's mediated by the atomic interaction," Lukin said. "That makes these two photons behave like a molecule, and when they exit the medium they're much more likely to do so together than as single photons."

While the effect is unusual, it does have some practical applications as

well.

"We do this for fun, and because we're pushing the frontiers of science," Lukin said. "But it feeds into the bigger picture of what we're doing because photons remain the best possible means to carry quantum information. The handicap, though, has been that photons don't interact with each other."

To build a quantum computer, he explained, researchers need to build a system that can preserve quantum information, and process it using quantum logic operations. The challenge, however, is that quantum logic requires interactions between individual quanta so that quantum systems can be switched to perform information processing.

"What we demonstrate with this process allows us to do that," Lukin said. "Before we make a useful, practical quantum switch or photonic logic gate we have to improve the performance, so it's still at the proof-of-concept level, but this is an important step. The physical principles we've established here are important."

The system could even be useful in classical computing, Lukin said, considering the power-dissipation challenges chip-makers now face. A number of companies – including IBM – have worked to develop systems that rely on optical routers that convert light signals into electrical signals, but those systems face their own hurdles.

Lukin also suggested that the system might one day even be used to create complex three-dimensional structures – such as crystals – wholly out of [light](#).

"What it will be useful for we don't know yet, but it's a new state of matter, so we are hopeful that new applications may emerge as we continue to investigate these photonic molecules' properties," he said.

More information: Paper: [dx.doi.org/10.1038/nature12512](https://doi.org/10.1038/nature12512)

Provided by Harvard University

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