Popular science account of

Making single photons interact using giant atoms

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Quantum technologies such as quantum communications or quantum computing that exploit the "weird" effects of quantum physics rely on robust carriers of information, so called qubits. Amongst different proposals, single photons are a viable candidate thanks to the vast amount of optical technology available and infrastructure in place for transmission such as fibre cables. However, the lack of interactions between photons which makes them useful as carriers of information – two rays of light will simply pass through, rather than bounce off each other – poses a serious challenge for information processing. One way to solve this is to temporarily "convert" the photons into gigantic, strongly interacting atoms, so called Rydberg atoms.

While interactions between two light beams seem impossible, there is a way around this problem. Typically, the effect of optical media and elements on a light beam is the same regardless of its power. Some media called non-linear media though react differently to different intensities. Here, interaction between the light and the material modifies the properties of the medium such that its effect on the light varies. This back action, however, only manifests itself if the incident light is very intense. Consequently, common non-linear media are not suitable to mediate interactions at the single photon level. To achieve strongly non-linear behaviour even between single photons, we convert them into other quantum objects that exhibit strong interactions and act as a memory for photonic qubits.

We chose to convert the photons into Rydberg atoms: atoms in which the outermost electron's orbit is on the order of a micrometre, a thousand times larger than the usual orbit. They behave as electrical dipoles, which are similar to magnets with their two poles, resulting in strong interactions between them over many micrometres. These lead to a characteristic effect crucial for applications in optical quantum technologies, the Rydberg blockade. Within a few micrometres only a single atom may be transferred to a Rydberg state.

In a first experiment we converted this Rydberg blockade between atoms into a blockade between photons. Two light beams were sent through a cloud of laser cooled atoms to excite them to a Rydberg state. One weak beam contained signal photons, which were to be stored as Rydberg excitations; the other was a stronger control beam that allowed us to change the speed of the signal photons in the cloud. As the intensity of the control beam is reduced to zero, the signal light comes to a stop and is effectively stored inside the atom cloud. In combination with the small dimensions of the cloud, the blockade limits the number of photons that can be stored to a few or even just a single one. By increasing the control beam power again, the stored photons can be retrieved and counted.

The ability to create single photons "on demand" is a prerequisite for use as qubits. But in order to process the information, further interactions that extend beyond the initially blockaded distance are necessary. Our future plan is to implement logic gates by storing multiple photonic qubits side by side, using microwaves to transfer them between different states. If the microwaves are weak they introduce even longer-range interactions. If the parameters are chosen correctly, the second blockade distance can be large enough to prevent the transfer to other states, thus allowing gate operations conditional on the presence of another qubit.

In order to reach this goal a few experimental challenges need to be overcome. However, we were already able to demonstrate the core mechanism of such a gate: the prevention of state transfer. When applying a weak microwave pulse on a single cloud containing on average three stored photons, we observed a reduction in the number of retrieved photons compared to the case without microwaves.

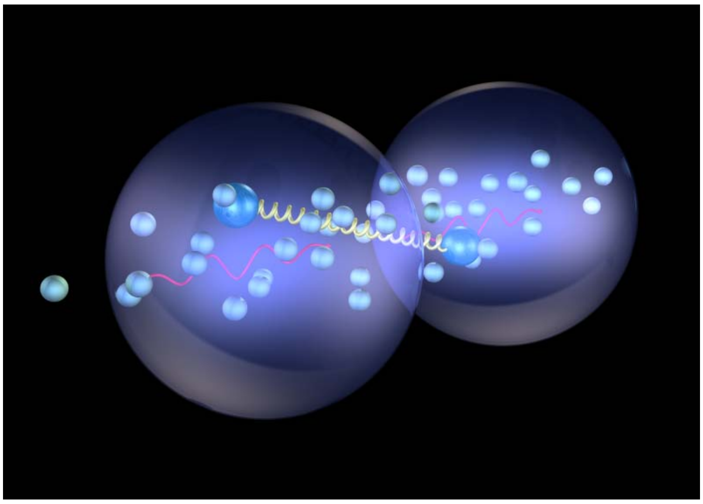

Figure 1: Two photons (red) are stored as Rydberg excitations inside a cold atom cloud. The transparent spheres indicate the blockaded region in which only one photon may be stored due to the Rydberg blockade.

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