Two molecules communicate via single photons

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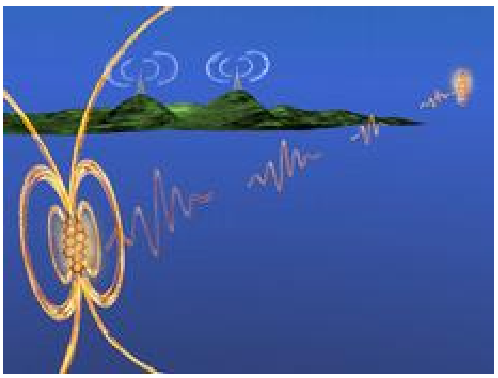

Artist's view of a single molecule sending a stream of single photons to a second molecule at a distance, in quantum analogy to the radio communication between two stations. Credit: Robert Lettow

Scientists realize one of the most elementary and oldest "gedanken" experiments in modern physics, namely, excitation of a single molecule with a single photon. This paves the way for further investigations in which single photons act as carriers of quantum information to be processed by single emitters.

We know since the dawn of modern physics that although events in our everyday life can be described by classical physics, the interaction of light and matter is down deep governed by the laws of quantum mechanics. Despite this century-old wisdom, accessing truly quantum mechanical situations remains nontrivial, fascinating and noteworthy even in the laboratory. Recently, interest in this area has been boosted beyond academic curiosity because of the potential for more efficient and novel forms of information processing. In one of the most basic proposals, a single atom or molecule acts as a quantum bit that processes signals that have been delivered via single photons.

In the past twenty years scientists have shown that single molecules can be detected and single photons can be generated. However, excitation of a molecule with a photon had remained elusive because the probability that a molecule sees and absorbs a photon is very small. As a result, billions of photons per second are usually impinged on a molecule to obtain a signal from it. One common way to get around this difficulty in atomic physics has been to build a cavity around the atom so that a photon remains trapped for long enough times to yield a favorable interaction probability. Scientists at ETH Zürich and Max Planck Institute for the Science of Light in Erlangen have now shown that one can even interact a flying photon with a single molecule.

Among many challenges in the way of performing such an experiment is the realization of a suitable source of single photons, which have the proper frequency and bandwidth. Although one can purchase lasers at different colors and specifications, sources of single photons are not available on the market. So a team of scientists led by Professor Vahid Sandoghdar made its own. To do this, they took advantage of the fact that when an atom or molecule absorbs a photon it makes a transition to a so-called excited state. After a few nanoseconds (one thousand millionth of a second) this state decays to its initial ground state and emits exactly one photon.

In their experiment, the group used two samples containing fluorescent molecules embedded in organic crystals and cooled them to about 1.5 K (-272 °C). Single molecules in each sample were detected by a combination of spectral and spatial selection. To generate single photons, a single molecule was excited in the "source" sample. When the excited state of the molecule decayed the emitted photons were collected and tightly focused onto the "target" sample at a distance of a few meters. To ensure that a molecule in that sample "sees" the incoming photons, the team had to make sure that they have the same frequency. Furthermore, the precious single photons had to interact with the target molecule in an efficient manner.

A molecule is about one nanometer is size (100000 times smaller than the diameter of a human hair) but the focus of a light beam cannot be smaller than a few hundred nanometers. This usually means that most of the incoming light goes around the molecule, i.e. without them seeing each other. However, if the incoming photons are resonant with the quantum mechanical transition of the molecule, the latter acts as a disk that is comparable to the area of the focused light. In this process the molecule acts as an antenna that grabs the light waves in its vicinity.

The results of the study published in *Physical Review Letters* provide the first example of long-distance communication between two quantum optical antennas in analogy to the 19th century experiments of Hertz and Marconi with radio antennas. In those early efforts, dipolar oscillators were used as transmitting and receiving antennas. In the current experiment, two single molecules mimic that scenario at optical frequencies and via a nonclassical optical channel, namely a single-photon stream. This opens many doors for further exciting experiments in which single photons act as carriers of quantum information to be processed by single emitters.

The experimental work was performed at ETH Zürich before the group of Prof. Sandoghdar moved to the newly founded Max Planck Institute for the Science of Light in Erlangen in 2011.

More information: Yves Rezus, Samuel Walt, Robert Lettow, Gert

Zumofen, Alois Renn, Stephan Götzinger, Vahid Sandoghdar, Single-photon spectroscopy of a single molecule, *Physical Review Letters*, 27 February 2012; DOI: 10.1103/PhysRevLett.108.093601

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