WINTER 2016

RIKEN RESEARCH

SHOWCASING THE BEST OF JAPAN'S PREMIER RESEARCH ORGANIZATION

www.riken.jp/en/research/rikenresearch

LORD OF THE RINGS

Spinning disk 100 times bigger than Saturn's

A LIGHT TOUCH
Single photon excites multiple atoms

DEPTHS OF DEPRESSION
World-first scan reveals where the blues are born

BREAKING WITCHWEED'S SPELL
Saving plants from parasitic invasion

ALL-TIME HIGH
Paired clocks measure elevation with precision

The team found that genes in licorice and related plants are strongly conserved. This indicates that legumes use a small number of genes to create ‘scaffolds’ that allow an enormous diversity of compounds to be produced.

“Chinese licorice is an important and heavily consumed medicinal plant,” says Keiichi Mochida, the first author of the paper. “We hope our work will make it possible to carry out molecular breeding to create strains that will grow sustainably in Japan and that will produce large concentrations of useful compounds such as glycyrrhizin.”

“We very much hope that our draft genome sequence will facilitate the identification, isolation and editing of useful genes to improve the agronomic and medicinal traits of licorice through molecular breeding,” says Saito. “There remains much to learn about the immense diversity of plant metabolism, and this research will contribute to further progress in that direction.”

The group plans to examine differences between the genome of *G. uralensis* and other licorice species in order to deepen their understanding of the production of useful compounds. ■

Reference

1. Mochida, K., Sakurai, T., Seki, H., Yoshida, T., Takahagi, K., Sawai, S., Uchiyama, H., Muranaka, T. & Saito, K. Draft genome assembly and annotation of *Glycyrrhiza uralensis*, a medicinal legume. *The Plant Journal* advance online publication, 24 October 2016 (doi: 10.1111/tpj.13385).

PHYSICS

Single photon excites two atoms at once

Calculations reveal how one particle of light can excite two atoms simultaneously

Our understanding of quantum optics has received a boost by the discovery, by RIKEN researchers, of a way to excite two atoms with only one light particle, or photon (see image)[1].

Franco Nori from the RIKEN Center for Emergent Matter Science leads a team exploring how light confined in small mirrored cavities makes atoms behave strikingly differently from free atoms. In particular, the electromagnetic forces generated by the light in a cavity induce the atom’s electrons to oscillate with the same frequency as the confined light. By tuning this so-called resonant frequency, scientists can trap atoms in high-energy excited states useful for quantum computing devices.

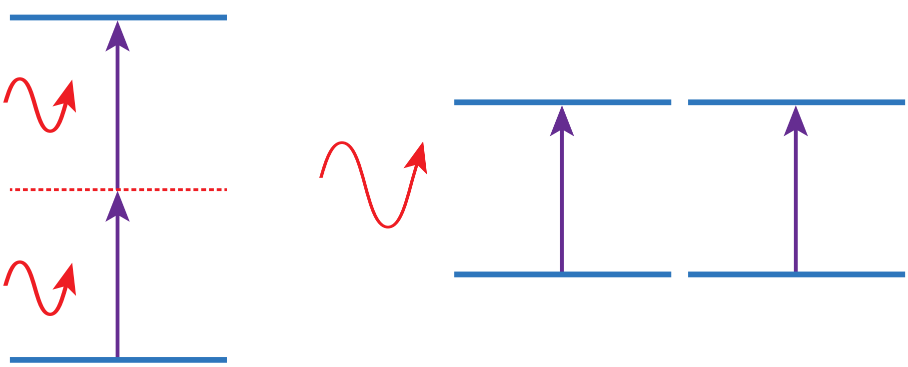
Intrigued by the possibility of using this ultrastrong coupling between the electromagnetic field and the atom’s electrons to excite multiple atoms with a single photon, Nori and colleagues in Italy modeled two identical atoms in a cavity. To their surprise, the calculations predicted that if the cavity’s resonant frequency is exactly twice the atom’s transition frequency to a higher energy state, each atom can take half the photon’s energy and jump to the higher energy state. The same effect can occur with three atoms when the resonant frequency is triple the atomic transition frequency.

Furthermore, the researchers discovered that the entire process should be reversible—multiple excited atoms in the cavity can relax by releasing a single photon.

Nori notes that the mechanism behind this process derives from the peculiar properties of light in a vacuum. “In effect, the system temporarily ‘borrows’ a second photon from the cavity,” he explains. “These ‘virtual’ photons are generated from chance fluctuations in the cavity’s vacuum. They appear and disappear all the time.”

The virtual photon helps the two-atom–one-photon system reach a new quantum state that combines two situations—one where both atoms are in their ground states with a photon in the cavity and another where the two atoms are excited and no photon is present. “Eventually, the system emerges from this blend of two states into purely the excited one,” Nori adds.

The researchers anticipate that this predicted phenomenon might be realized experimentally with superconducting ‘artificial atoms’ that have precisely engineered energy levels.



In two-photon absorption, two photons excite a single atom or molecule (left). Theoretical models show that one photon can excite two or more atoms or molecules (right). Photons represented by red arrows; atoms represented within blue lines.

"This process might lead to useful spectroscopic and diagnostic tools, but the details will take time," says Nori. Furthermore, excitation of two atoms by a single photon could produce quantum states in which more than two particles are entangled, which would be useful for quantum cryptography and computation.

Reference

1. Garziano, L., Macrì, V., Stassi, R., Di Stefano, O., Nori, F. & Savasta, S. One photon can simultaneously excite two or more atoms. *Physical Review Letters* **117,** 043601 (2016).

CHEMISTRY

Probing energy transfer using light

A new method for scrutinizing the energy transfer between molecules promises to improve our understanding of photosynthesis and further the development of energy harvesters

An all-RIKEN team has developed a powerful method for probing energy transfer, which could assist the development of energy-harvesting devices and unlock the secrets of photosynthesis.

The process of photosynthesis, by which plants convert sunlight into chemical energy, involves a minutely choreographed transfer of energy between molecules. But exactly how the energy is moved is not fully understood because it is highly challenging to observe these transfers, which occur extremely rapidly and on a very small scale.

Scientists have previously attempted to map how molecules become excited and pass on these excitations to other molecules. But they used optical spectroscopy, which relies on regular light waves and cannot see phenomena smaller than several hundred nanometers. It thus cannot detect many of the transfers, which occur at a nanometer scale.

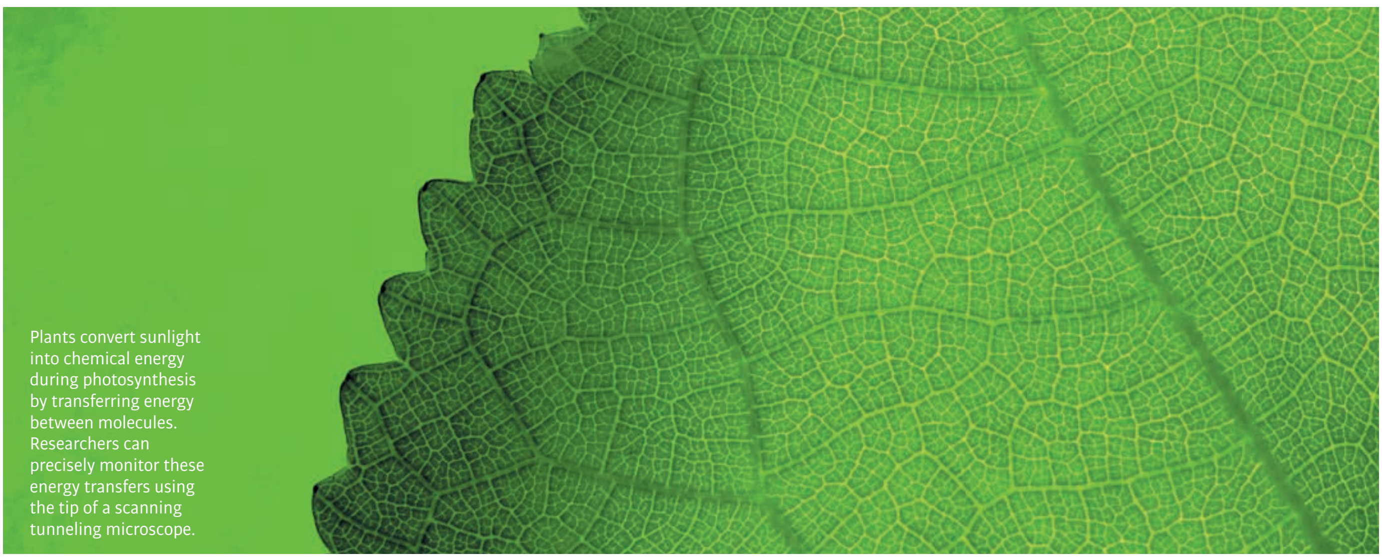
Now, Yousoo Kim and colleagues at the RIKEN Surface and Interface Science Laboratory have developed a powerful observational method to catch these transfers in action. It employs absorption and emission spectroscopy combined with a scanning tunneling microscope (STM).

The researchers used this method to observe energy transfer between two molecules—free-base phthalocyanine (H2Pc) and magnesium phthalocyanine (MgPc)—which emit fluorescent light at different energies. When they precisely stimulated the MgPc molecule alone with electrons from the STM tip, they detected luminescence signals from a nearby H2Pc molecule, clearly indicating that energy transfer from MgPc to H2Pc had occurred.

The team showed that the mechanism behind the process is resonance energy transfer, a form of transfer where energy is transmitted by resonance, in the same way that tuning forks will begin to vibrate together when they are tuned to the same frequency, rather than charge transfer from one molecule to another through shared electrons.

The researchers also demonstrated the possibility of using a single-molecule valve device for energy transfer based on a transition between different chemical forms, known as tautomers, of H2Pc, which could be seen as the energy transfer switched on and off like a blinking light.

"Using this technique, we have shown that it is possible to pinpoint how energy is transferred between molecules," says Kim. "This work could be used to design new



Plants convert sunlight into chemical energy during photosynthesis by transferring energy between molecules. Researchers can precisely monitor these energy transfers using the tip of a scanning tunneling microscope.