by the same proteins. Their data also indicate that, during evolution, photoprotection arose before the appearance of highly efficient light-harvesting proteins.

Li and colleagues go on to show that the presence of PsbS is required for a conformational change in the photosynthetic membrane that engages thermal energy dissipation. At the same time, this conformational change also requires zeaxanthin and a pH gradient across the photosynthetic membrane. The authors discuss several models that could accommodate these findings. One attractive possibility is that protonation-dependent structural changes in PsbS facilitate downhill energy transfer from over-excited chlorophyll to zeaxanthin, followed by the rapid loss of this excitation energy from zeaxanthin in the form of heat, as is characteristic for carotenoids but not for chlorophylls.

What next? We now need to identify the exact location of the PsbS protein within the supramolecular structure of light-harvesting proteins. We also need to find out whether PsbS is, indeed, the site of thermal energy dissipation and the binding site for a specialized zeaxanthin molecule that facilitates most of the thermal dissipation. Alternatively, PsbS and the structural change in which it is involved may catalyse zeaxanthin-dependent energy dissipation in other components of the light-collecting system.

Li *et al.* suggest that PsbS synthesis may increase in leaves exposed to higher levels of excess light on a daily basis. Before its function was known, increased levels of PsbS had also been observed[3] in needles of Scots pine (*Pinus sylvestris* L.) in winter. These results show that we need to examine the involvement of PsbS in acclimation to the environment, where it probably modulates the maximal capacity for protective energy dissipation as needed. All of these questions should provide an exciting avenue for future research. ■

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Nanotechnology

One photon seen by one electron

Leo Kouwenhoven

Single photons can easily be detected by photomultipliers if their wavelength is much shorter than a micrometre. Photomultipliers contain photosensitive material inside a vacuum tube that produces a cascade of electrons when a photon strikes. This transformation from a single photon to many electrons works well in the visible and near-infrared range, but not for single photons of longer wavelengths.

Using a single-electron transistor as a detector, Komiyama *et al.*[1] report, on page 405 of this issue, measurements with unprecedented sensitivity for far-infrared (FIR) photons with wavelengths of several hundred micrometres. Such a detector is of great interest to spectroscopic research in the FIR region, which covers the vibrational spectra of molecules in liquids or gases, and there are many applications in astronomy, biochemistry and atmospheric research. The approach followed by Komiyama *et al.* marks a breakthrough because it provides single-photon sensitivity and simultaneously measures the wavelength of the photon.

There have been decades of research on quantum detection at submillimetre wavelengths[2] but, although detectors do exist in this regime, none have single-photon resolution[3]. A little thought about how individual quantum particles can be detected with a classical apparatus leads to the realization that this is far from trivial. What is actually happening inside a detector where at one end a particle, such as a photon, enters and at the other end a visible signal appears on a display? Somewhere inside, the small signal from the individual photon must have been immensely amplified to produce an electrical signal of around 10^{16} electrons per second (that is, milliamperes). This giant amplification should be accompanied by such a low noise level that unwanted errors do not occur — in other words, if there are no photons, there should be no signal. This becomes increasingly difficult for photons with smaller energy.

The energy range for submillimetre FIR radiation is somewhere between 1 and 100 millielectron volts (meV). As an example, a photon with a wavelength of 0.1 millimetres has a frequency of 3 terahertz and an energy of 12 meV. (For comparison, visible light is between 1.6 and 3.3 eV.) So, to obtain wavelength selectivity, the detector should be sensitive in this energy range. To do this, Komiyama *et al.*[1] used cyclotron resonance between two Landau levels (Fig. 1). The Landau levels are narrow bands of allowed electronic states, which arise in a two-dimensional electron gas subjected to a large magnetic field. (In electron transport, the Landau levels lead to the quantized Hall effect.) Photon absorption can occur only when the photon energy equals the energy difference between the Landau levels. Under an applied magnetic field the energy separation changes by ~2 meV per tesla. So the magnetic field provides a knob to select a certain photon energy. Moreover, it transfers the signal of a single photon into an excitation of a single electron.

The next step is the detection of this photo-excited electron. Nowadays it is relatively simple to measure individual electrons by using single-electron transistors (SETs)[4]. These transistors are so small that the presence or absence of a charge from a single electron can switch the current on or off through the transistor. SETs can be made from metals or from semiconductors, in which case they are called quantum dots[5]. In fact, Cleland *et al.*[6] have already reported single, FIR-photon detection using a metallic SET integrated with a silicon semiconductor structure. The

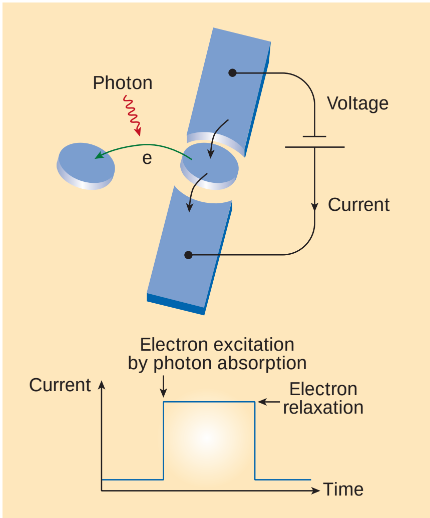

Figure 1 **Single-photon detection by a single-electron switch, as demonstrated by Komiyama *et al.*[1]. A quantum dot in the shape of a thin disk (typical radius of 100 nm) is connected through two electrodes to an external current and voltage circuit. In the presence of a high magnetic field, the electronic states of the quantum dot can be represented as two disks separated in space[5]. Initially the current is zero, owing to Coulomb blockade in the quantum dot. When a FIR photon (red arrow) excites an electron (green arrow), Coulomb blockade of the central disk is removed and current can flow (black arrows). The current switches to zero when the electron relaxes back to the central disk. The quantum dot is now ready to detect the next photon.**

experiment by Komiyama *et al*. has much improved noise, but most importantly it is frequency, or equally wavelength, selective.

This new FIR detector will never be as easy to use as the table-top photomultiplier. It needs to be cooled down to very low temperatures, for two reasons. First, the FIR-photon energy is much lower than the thermal energy at room temperature (which is 25 meV at 300 K). This means that unwanted, background photons from room-temperature blackbody radiation will dominate the detector signal. To suppress the influence of blackbody radiation, the detector is cooled below 1 K. Second, the quantum dot used by Komiyama *et al*. operates properly only below about 1 K (ref. 5), so the detector will always need to be inside a helium cryogenic system. However, this is true for all sorts of FIR detectors, including those based on superconductivity[3].

After any demonstration experiment, many hurdles to developing a useful product remain. In this experiment on single-photon detection, not only the detector but also the radiation source was cooled to low temperatures[1]. This is not practical for many spectroscopic applications, such as in vibrational spectroscopy of biological molecules. Fortunately, interstellar gases are naturally cooled to about 3 K so their radiation can be measured by using the detector outside the Earth's atmosphere. ■

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Global change

Rice, microbes and methane

Joshua Schimel

Methane is present at about only 1.8 parts per million in the atmosphere, but is a key player there — it is a greenhouse gas, it is central to atmospheric oxidation chemistry, and it is ultimately a source of stratospheric water vapour, which influences ozone depletion. Moreover, the concentration of methane is increasing rapidly. Hence the interest in the paper by Bodelier *et al.*, on page 421 of this issue[1], which deals with methane emissions from rice paddies.

Most of the methane in the Earth's atmosphere comes from biological processes, and rice paddies are one of the main sources. A large fraction of the methane produced in rice soils is consumed, however, being oxidized to carbon dioxide by methane-oxidizing bacteria (methanotrophs) in the soil, and so never makes it to the atmosphere. In upland soils, ammonium, which is formed naturally but is also a major constituent of nitrogen fertilizers, can inhibit methane oxidation and methanotroph growth. It has been a common assumption that this should occur in other ecosystems as well. So it comes as a surprise that Bodelier *et al.* find that, in rice-paddy soils, ammonium actually stimulates methane oxidation and methanotroph growth. This phenomenon may dominate the overall response of methane cycling to fertilization in rice-paddy ecosystems.

According to current estimates, rice agriculture will expand by up to 70% over the next 25 years to support the growing human population[2]. This will involve both increasing the area under cultivation and maximizing productivity by crop breeding and fertilizer management. Until now, it was thought that using nitrogen fertilizers on rice would increase trace-gas emissions. When nitrate-based fertilizers are used, much of the nitrate is denitrified, causing increased emissions of nitrous oxide, another potent greenhouse gas and ozone depleter. Ammonium fertilization also has the potential to increase methane emissions[3] — not only does it increase plant growth and carbon flow to methane-producing bacteria (Fig. 1a, overleaf), but it can also inhibit methane oxidation (Fig. 1c).

How does ammonium inhibit methane consumption? Several explanations have been proposed, the most solidly substantiated of which is competitive inhibition at the enzyme level[4,5]. This occurs because, at the molecular scale, methane and ammonium are similar in size and structure. As a result, the enzyme that oxidizes methane (methane monoxygenase) can bind to ammonium and react with it (Fig. 1c). Because the possibility of competitive inhibition is fundamental to the biochemistry of methane oxidation, it was generally thought that inhibition should occur in rice paddies as well as in upland systems. In fact, it may, and the work of Bodelier *et al*. does not rule it out.

However, the extent of competitive inhibition is proportional to the ratio between

100 YEARS AGO

Expressions of opinion from political leaders as to the value of scientific advice, and the need for scientific methods in Government Departments, are so rare, that some remarks which Lord Rosebery made upon this subject at Chatham on Tuesday come almost as a surprise. We have over and over again referred to the lack of interest in the progress of science, and the disinclination to take advantage of available applications, shown by official authorities concerned with national affairs. Only recently some of the scientific lessons taught by the [Boer] war have been pointed out in these columns… and some of the services which a committee of men of science could render to the Government if their advice were asked have been indicated. From the subjoined extract from Lord Rosebery's speech it will be seen that he is in accord with the methods advocated in these columns. If the war leads to an acknowledgement of the value of scientific opinion, the result will be one upon which the nation may be sincerely congratulated.

From *Nature* 25 January 1900.

50 YEARS AGO

In the United States, wildfowl have been suffering from epidemic diseases, and, though there is no reason to believe that any such epidemics are likely to occur in the British Isles, investigations are being made into causes of mortality among wildfowl in Great Britain. Comparatively few wild ducks are picked up dead; but should any carcasses be found it is possible that the birds may have died from some disease and that a post-mortem examination would be of value. Carcasses should be forwarded to the Pathologist, Prosectorium, Zoological Society of London… as quickly as possible after finding, as the longer the post-mortem examination is delayed the less likelihood there is of determining the cause of death. The birds should be carefully wrapped in paper and packed in a box in order to comply with an international post office agreement, which stipulates that there must be no leakage from pathological specimens. The name and address of the sender, the place, and the locality and date of finding should be enclosed in the parcel. Postage will be refunded. Birds affected by oil should *not* be forwarded.

From *Nature* 28 January 1950.