or countries, such as those that are currently plaguing economies around the world. ■

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PHYSICS

Manipulating individual quantum systems

Serge Haroche and David J. Wineland have been awarded the Nobel Prize in Physics for developing techniques to measure and manipulate single particles without destroying their quantum properties. Haroche traps photons and measures and controls their quantum states with atoms. Conversely, Wineland traps ions and controls them with light (see figure).

SINGLE-PHOTON CONTROL
by Ed Hinds

Serge Haroche and his colleagues have developed an experiment to study the quantum mechanics of microwave light trapped between two mirrors (a cavity)[1]. They show that the quantum of light — the photon — can be controlled at an astonishing l evel of precision, and have used this to bring the abstract ideas of quantum entanglement to life in the laboratory.

Light is usually detected by destroying it: for example, a light sensor called a photodiode generates an electrical pulse when it absorbs, and so destroys, a photon. But Haroche's group measures the intensity of trapped light using a non-destructive method that probes the light using atoms flying through the trap. Each atom acts as a clock whose ticking rate depends on its energy level. As an atom flies through the cavity, its energies are shifted by the trapped light, and the total number of ticks of the clock changes accordingly, without any light being absorbed.

When a kind of excited atom called a Rydberg atom is used, the technique is sensitive enough to detect a single photon, and repeated measurements allow the same photon to be observed as it lives and eventually dies in the cavity[2]. Similarly, starting with several photons, the researchers can watch the photons disappearing one by one as they are absorbed by the cavity mirrors. The group has even prepared photons in a 'Schrödinger's cat' state — a fragile quantum state in which many photons are collectively doing two things at once (being dead and alive in the case of the cat) — to study how the state is destroyed by photon loss in the cavity[3]. These studies allow deep insight into the way quantum systems work, and provide a practical basis for developing powerful devices based on the strange laws of quantum mechanics.

MASTERING SINGLE IONS
by Rainer Blatt

A consummate experimentalist, David Wineland pioneered the use of electromagnetic devices known as Paul traps to hold single trapped ions for quantum metrology. Along the way, he has developed a plethora of groundbreaking experimental methods that have since become standard means of manipulating single atoms.

Armed with efficient single-atom detection through a technique called electron shelving, together with laser cooling to bring an ion to its lowest-energy vibrational state, Wineland masterfully conducted ultra-high-precision spectroscopy of single ions. Using precisely timed and tuned laser pulses, he tailored the coupling between the ions' internal states and their quantized vibration[4].

Notably, it is with this technology that he laid the groundwork for unprecedented control of a single trapped particle's electronic and motional degrees of freedom, which he in turn applied to generate many kinds of non-classical states that could otherwise be observed only through light–matter interactions in a cavity[5].

These methods culminated in Wineland's quantum-logic clock, in which the ions' motion is used to transfer otherwise inaccessible spectroscopic information to a read-out ion[6]. This technology has produced the most precise measurement of an atomic frequency ever obtained, with a fractional uncertainty of less than 10^{-17}. Moreover, Wineland's spectacular quantum mastery will continue to have a major impact. His techniques are already a crucial element of the exciting field of quantum information processing, and will prove invaluable for both fundamental tests of quantum physics and future quantum technologies. ■

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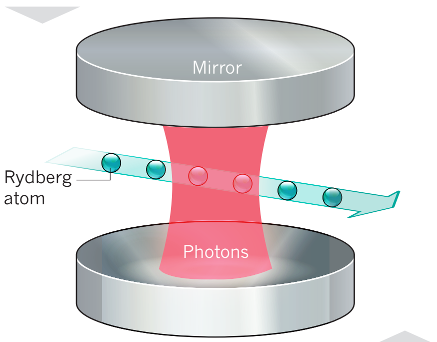
HAROCHE METHOD

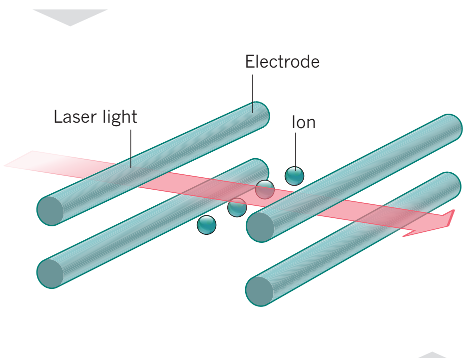
Microwave photons are placed between two highly reflective mirrors that enable an individual photon to bounce back and forth between them many times.



Rydberg atoms, which have one electron in a high-energy level, are sent through the system to measure and manipulate the photon's quantum state.

WINELAND METHOD

An electric field produced by an arrangement of electrodes holds one or several ions inside a trap.



Laser light is shone on the ion, suppressing its thermal vibration and allowing its quantum state to be measured and controlled.