Squeezing Light for Precision, Speed

Known a decade ago only to theorists, the peculiar quantum-mechanical state called squeezed light now appears to have a bright future in high-precision studies of atoms and in ultrasensitive instruments for detecting acceleration. By using this novel form of light, researchers can partially suppress the randomness associated with any quantum process, thereby lowering the quantum fluctuations, or noise, that normally accompany signals used to make measurements.

"Not only can we squeeze light, but we can now do it reliably enough to do spectroscopy with it," says physicist H. Jeffrey Kimble of the California Institute of Technology in Pasadena.

In the May 18 PHYSICAL REVIEW LETTERS, Kimble and co-workers John Carri and Eugene S. Polzik describe the application of squeezed light to the detection of a particular transition from one electron energy level to another in a cesium atom. This study represents an early step into a hitherto unexplored quantum realm where only theorists dared tread — a world of one-dimensional atoms and unusual interactions between atoms and light.

The concept of squeezing light originates in the notion that empty space, or the vacuum, is not really empty at all but filled with a sea of randomly fluctuating electromagnetic fields. According to the Heisenberg uncertainty principle, it's impossible to specify with absolute precision the energy of any system. Hence, even the vacuum exhibits tiny fluctuations in energy that constitute a sort of intrinsic background noise.

These so-called vacuum fluctuations have a discernible effect on light. For example, light emanating from even the best lasers displays irregularities, known as "shot noise," which reflect the influence of the quantum background and set a strict limit on the precision of any measurement made using this light.

But there's a way around the uncertainty principle that involves trading off knowledge about the number of photons present in a light beam against knowledge about the spacing of these photons. When picturing light as a wave, these complementary aspects of photon number and spacing correspond to a light wave's amplitude (height) and phase (roughly speaking, crest position).

To generate squeezed light, researchers deliberately reduce the uncertainty in one component (either the amplitude or the phase of a light wave) at the expense of the other. By using the more predictable component, which displays less extreme fluctuations than even the vacuum, researchers can substantially improve the sensitivity of their measurements (SN: 3/10/90, p.151).

Kimble and his colleagues developed a remarkably stable source of squeezed light that can be tuned over a broad range of frequencies. Operating their source at wavelengths around 852 nanometers, they used it to detect a particular energy-level transition in atomic cesium, cutting by more than half the amount of quantum noise that normally contaminates such measurements.

"Enhanced detection sensitivity should be readily attainable for atoms and molecules other than [cesium] and could lead to improved capabilities beyond the shot-noise limit in a variety of spectroscopic investigations," the researchers conclude.

The same source of squeezed light may also serve as a means of fundamentally altering the way atoms themselves radiate light. However, a major obstacle in the way of achieving such effects is the mismatch between a three-dimensional, vacuum-immersed atom and the narrow beam of squeezed light that illuminates it.

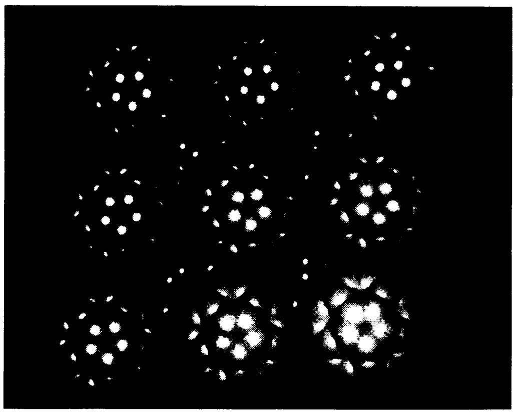
To improve the efficiency with which squeezed light interacts with an atom, Kimble and his colleagues are developing a mirrored trap, or cavity, within which atoms behave as if they were one-dimensional. "We can put an atom in a cavity, shine squeezed light on it and study the resulting radiative processes," Kimble says.

Hermann A. Haus and his collaborators at the Massachusetts Institute of Technology have a different, more practical goal in mind for squeezed light. Sending light along different paths and then reuniting the beams produces a distinctive interference pattern of dark and light bands where the beams overlap. By incorporating such an interferometer and a source of squeezed light into a semiconductor chip, engineers could readily monitor minute, rapid changes in the velocity of any vehicle or instrument carrying the chip and achieve an unprecedented level of sensitivity in acceleration measurements. *— I. Peterson*

Serendipity yields buckyball trap for gases

The word serendipity often pops up when scientists talk about buckyballs. In fact, chance has proven almost as important as planning in many recent experiments involving these soccerball-shaped, 60-carbon molecules of the fullerene family.

For example, chemist Douglas A. Loy at the Sandia National Laboratories in Albuquerque, N.M., says he and his co-workers were inspired to make the first buckyball polymer (SN:12/14/91, p.391) only after Loy happened to catch a remark made at a conference.


Sandia National Laboratories

Computer model depicting a buckyball crystal with the smaller oxygen molecules squeezed into the spaces between the larger 60-carbon molecules.

Now a different group at Sandia reports another lucky bucky discovery. Chemist Roger A. Assink and colleagues were studying a pure, buckyball crystal with nuclear magnetic resonance (NMR) spectroscopy when they saw something odd: two lines in the spectrum. Since one spectral line normally indicates a pure buckyball crystal, two lines baffled Assink and his team at first. "We were quite concerned about what we really had," he says.

Later, however, the researchers found their sample wasn't pure after all. The extra line showed up in the crystal's spectrum because oxygen molecules had sneaked into gaps between the buckyballs in the crystal. Moreover, when Assink's team exposed another buckyball crystal to pressurized oxygen, they found that the crystal's NMR spectrum showed not one, but six lines, indicating that as many as six oxygen molecules had squeezed into the spaces around individual buckyballs. The group's findings will appear in an upcoming JOURNAL OF MATERIALS RESEARCH.

Interestingly, when the researchers exposed the buckyball crystal to gases other than oxygen, they discovered that the sample absorbed only certain ones. "Getting in and out of these crystals seems to depend on how big the gas molecule is," Assink says. For example,