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.

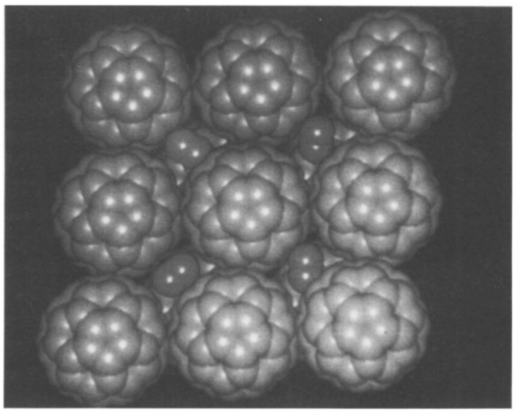
To improve the efficiency with which squeezed light interacts with an atom, Kimble and his colleagues are developing a mirrored trap, or cavity, within which atoms behave as if they were one-dimensional. "We can put an atom in a cavity, shine squeezed light on it and study the resulting radiative processes,"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



Sandia National Laboratories

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

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.

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, the sample could absorb molecular hydrogen but not methane, a much larger molecule.

A discriminating crystal could prove useful to industry, the scientists say. For instance, commercial natural gas, or methane, often contains impurities, such as nitrogen, which must be removed before the gas can be used as a fuel, Assink notes. A thin film containing buckyball crystals might act to filter out any contaminating gas, he adds.

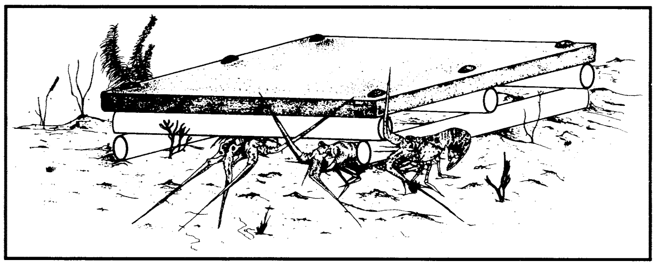
Assink's group also found that soon after entering the crystal, the gas molecules begin to vacate it, although at a much slower pace. "If you put in a lot of oxygen, even after 25 days approximately half of the oxygen is left," Assink reports. The crystal's ability to release trapped gas over time might also lend itself to industrial applications, the researchers assert.

The scientists believe that manipulating either the buckyball molecule or its crystal geometry might also allow them to vary how many and what kinds of gas molecules a crystal will hold, as well as the release rate of those gases.

The Sandia team's findings have implications for future buckyball research as well, Assink says. Some supposedly pure buckyball crystals might actually contain enough gas molecules to throw an experiment off. "No matter how tight you pack the buckyballs, there are going to be vacancies – holes – within the crystals," he notes.

Both Assink and Loy assert that for chemists and materials scientists, the buckyball bonanza is still going strong. "In the fullerene business, it's pretty much open season," Loy says. Moreover, "a lot of the serendipitous stuff that's been falling out may surprise the devil out of you." – *M. Stroh*

Spiny lobsters: There's safety in numbers



Eggleston & Lipcius/Ecology

Spiny lobsters inhabiting a casita.

Spiny lobsters are party animals. Juveniles and adults tend to congregate in groups of 10 or more in large crevices within coral reefs or in roomy gaps between the seafloor and the rotting planks of old shipwrecks. But this relatively open, gregarious lifestyle would seem to leave the lobsters more vulnerable to predators than going it alone in a hole sized for one, where larger animals such as sharks would have a tougher time reaching them.

Now, two fisheries ecologists have found evidence that spiny lobsters' socializing may in fact help them elude predators. The new study suggests that the lobsters developed their gregarious habits to avoid ending up as lunch.

David B. Eggleston and Romuald N. Lipcius of the Virginia Institute of Marine Science in Gloucester Point, spent a year and a half studying the shelter preferences of spiny lobsters off the gulf coast of Mexico. They began their experiments to determine whether the artificial dens, called *casitas*, used by many Caribbean fishermen to attract lobsters for harvest, rendered the lobsters more open to attack by predators, thereby reducing the harvestable number.

In the June Ecology, Eggleston – who now works at the University of Washington in Seattle – and Lipcius report the results of two types of experiments on lobster behavior. In the first, they observed lobsters in man-made enclosures; in the second, they monitored the shelter choices of lobsters in the wild.

To conduct the enclosure experiment, Eggleston and Lipcius built a 20-foot-wide pen of wire mesh and placed it offshore in water roughly four feet deep. Into the pen they placed a small, a medium and a large *casita* constructed of plastic pipes and concrete slabs. The openings of the *casitas* were scaled to admit only small, medium and large lobsters, respectively.

When Eggleston and Lipcius placed a lone male spiny lobster in the pen, they found that it sought shelter underneath the *casita* that best fit its body size. But when the researchers put nine male lobsters into the pen together, most of the lobsters congregated beneath the largest *casita*.

To investigate what would happen in the presence of a potential predator, the researchers repeated the experiment after placing a five-foot-long nurse shark into the pen. This time, they found that the lone lobster crammed itself into the smallest possible *casita* in order to stay out of harm's way. Similarly, the group of nine lobsters tended to gather in the medium *casita* rather than the large one.

Eggleston and Lipcius observed similar shelter choices among spiny lobsters in the wild. They conclude that such gregarious behavior helps the lobsters survive.

"This confirms that predation risk is what's driving [the lobsters'] shelter use pattern and suggests their sheltering behavior has evolved as a result of predation pressure," Eggleston asserts.

He speculates that by grouping together, spiny lobsters increase their chances of spotting an approaching predator, while decreasing their likelihood of being the lobster that gets eaten. Moreover, he says, groups of lobsters often cooperate to fend off smaller predators by backing into a circle and using their spiny antennae to swat intruders.

Biologist William G. Lyons of the Florida Marine Research Institute in St. Petersburg says the study "documents . . . the effectiveness of gregarious behavior." He says there's no other reason why lobsters of the same sex might gather: "There's no Friday night poker game or anything like that." – *C. Ezzell*

Cells melt mouse tumors

Studies suggesting that the naturally occurring substance interleukin-2 boosts the immune system's response to cancer prompted a research team to engineer cells to fight tumors in mice.

Robert E. Sobol of the San Diego Regional Cancer Center and his colleagues hoped that by inserting the gene that codes for interleukin-2 into mouse cells, they could produce cells that would secrete interleukin-2. These cells would then spur the immune system to destroy malignant tumors in the animals.

To test this theory, the team engineered interleukin-2-producing mouse cells, put the altered cells and some tumor cells in a solution and injected the mixture into 10 mice. They gave another group of 10 mice injections of tumor cells and unaltered cells. The scientists knew that tumor cells by themselves would spur an immune response, but they wanted to compare it with the immune rally sparked by interleukin-2. Seven control mice got injections of saline solution.

Two weeks later, the San Diego team implanted a small tumor just under the skin of each mouse in the study. Twenty-eight days after implanting the tumors, the scientists discovered that six of the 10 mice that had received the engineered cells showed no sign of cancer. The ten mice that received injections of unaltered and tumor cells showed a weak anti-tumor response – most had tumors that shrank in size. In contrast, all seven mice given only saline injections had tumors that got larger during the same period.

Sobol reported his team's data last week at the American Association for Cancer Research meeting held in San Diego. The team wants to try the same approach with human cancer patients. □