Playing Ball With Laser-Cooled Atoms

Once you have tamed an atom by cooling and trapping it with lasers (see main text), you can make it do all kinds of tricks. You can make it resonate with a beam of microwaves to set an accurate frequency standard for time, or force it to rise and fall in an atomic fountain. And when trapping is combined with an ingenious atomic mirror, a group in Claude Cohen-Tannoudji's laboratory at the Ecole Normale Supérieure in Paris has shown, you can even bounce an atom over and over again like a minute rubber ball.

For now, says Jean Dalibard, the leader of the Paris team, the group is just practicing the trick. But once they have polished it, they hope to exploit the fact that when atoms move slowly enough—and the bouncing atoms are, by the standards of most atomic physics, glacially slow—their quantum-mechanical wave nature emerges. The bouncing atoms should resemble reflected light, and, like reflected light, they should interfere with themselves. And just as devices based on optical interference can serve as fine measuring tools, an interferometer based on atoms could serve as the basis for an exquisitely sensitive gauge of acceleration or gravity.

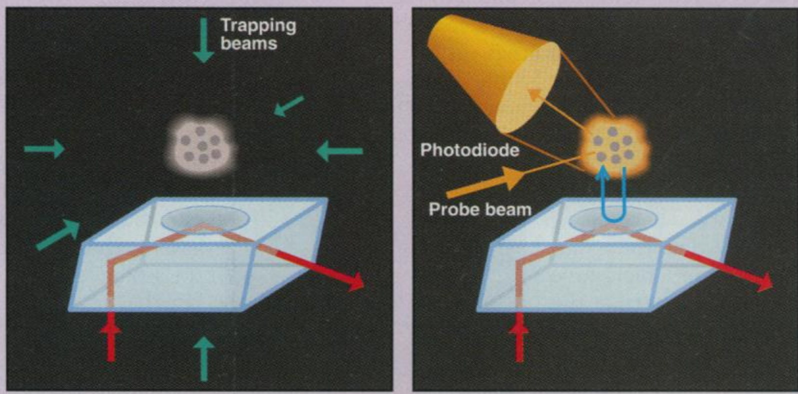
The kind of optical device, known as a Fabry-Perot interferometer, that Dalibard's group hopes to mimic requires a pair of mirrors, which create an optical "cavity" in which light is reflected back and forth. If the mirrors are separated by an exact multiple of half the wavelength of the light, the light overlaps with itself to create an apparently stationary interference pattern, or standing wave, that is extremely sensitive to anything that affects the propagation of the light. To build the atomic analogue of such a device, the Ecole Normale group realized, they would only have to reflect the atoms at one end; providing the device was vertical, gravity would take care of the other, as the atoms rose and fell.

The starting point is a laser trap that holds about 10^7 chilled cesium atoms. To bounce the atoms, the researchers turn off the trapping lasers and let the atoms fall the 3 millimeters onto a concave depression cut in the top of a block of glass. Since atoms falling onto an ordinary glass mirror would simply stick to it, the researchers had to enlist a technique for reflecting atoms with light, first suggested by other researchers in the early 1980s.

Another laser beam passes through a channel in the block and is reflected off the inside surface of the curved mirror. This light beam creates an alternating electric field outside the glass, just above the surface of the mirror, known as an evanescent wave. The laser beam, and hence the evanescent wave, is tuned to a frequency to which cesium atoms are particularly sensitive. As an atom falls into the evanescent wave, the electric field alters the spacing of the atom's quantum-mechanical energy levels, raising its potential energy. Like a ball rolling uphill, the falling atom experiences a force that pushes it away from the steadily increasing field. If the force is strong enough, the atom never touches the glass but bounces out of the field. Eventually gravity takes over, the atom drops back into the field, and then bounces out once again.

To detect the bouncing atoms, the researchers shine a probe laser beam above the mirror. This beam is tuned to a frequency at which the atoms fluoresce. The stronger the fluorescence, presumably, the more atoms have bounced up from the mirror. Because the probe beam knocks all the atoms off course, the researchers have to repeat the experiment, probing for cesium atoms at different times. The result: After the atoms were dropped, the area above the mirror was first empty, then full of atoms, then empty again, at intervals of 50 milliseconds—the time for one bounce. As the group reported in the 8 November *Physical Review Letters*, they have managed to sustain up to 10 bounces so far.

These bouncing atoms are not quite ready to serve as a Fabry-Perot interferometer, says Dalibard. Even though the atoms are cooled close to absolute zero before being dropped, they still have some residual velocity. An atomic interferometer needs all the atoms at the same velocity so that their wavelengths are identical and in step. That will take more work, Dalibard says. In the meantime he and his colleagues are refining their technique: "Thirty to 40 bounces is not hard on paper," he says.



Caught on the rebound. A cloud of atoms, released from a laser trap *(left)*, bounces off an atomic mirror and is detected by probe laser *(right)*.

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Further in the future there is an even more tantalizing possibility. A resonating optical cavity is the basis of a laser, which produces coherent light. An atomic cavity could, in theory, produce a coherent beam of atoms, which could probe material surfaces. But a few details still need to be worked out, Dalibard concedes. For one thing, "atom laser" is a bit of a misnomer, since the "l" stands for light. "We're still looking for the right acronym," he says.

–Daniel Clery

Tannoudji's group, including Gilbert Grynberg, has been arranging multiple "microtraps" in a three-dimensional array, which may eventually allow them to study how atoms interact over long distances. They build the array by arranging four laser beams in a pyramid-like configuration to interfere with one another, creating a three-dimensional array of regions in which the electric field is alternately strengthened and weakened. This effect tends to trap atoms in what Cohen-Tannoudji calls an optical lattice. "By varying the size of the lattice," says Cohen-Tannoudji, "we can hope to observe how effects [such as quantum-mechanical interactions between neighboring atoms] change as a function of distance."

But even Cohen-Tannoudji acknowledges that there are limits to how refined laser cooling and trapping can get. Cohen-Tannoudji's ultra-chilled atoms, for instance, are so easily disturbed that the group has had to start performing experimental runs in the middle of the night to avoid the stray electromagnetic fields from nearby subway trains. Who would have thought objects that ordinarily travel nearly as fast as the Concorde could one day be so still as to be disturbed by the Metro?

–David H. Freedman

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