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Whipping up atomic crystals bound by light

Chill atoms to microkelvin temperatures, then trap them in the diaphanous folds of an undulating blanket of light created by overlapping laser beams. This recipe for an optical crystal sounds simple, but preparing such a novel concoction requires considerable care. The result is a new kind of short-lived solid.

"We have a new state of matter in which atoms are located in a crystal [lattice] induced by light," says Gilbert Grynberg of Pierre and Marie Curie University in Paris. Such optical crystals have the same overall orderliness as ordinary crystals, but the positions of individual atoms are determined not by forces between atoms but by the wavelength of the confining light.

Moreover, each atom is confined to such a small region that its motion is quantized. In other words, the trapped atoms jiggle back and forth within their quantum cages at only certain frequencies.

Last year, two groups of researchers working independently reported using laser-generated standing light waves to arrange cold cesium and rubidium atoms into long rows. Measurements of how the trapped atoms interact with light confirmed that these atoms are spaced in such a way as to behave as a one-dimensional optical crystal. These measurements also revealed that the trapped atoms vibrate at particular frequencies.

"This was the first observation of quantized levels of a neutral atom in an optical field," notes Claude N. Cohen-Tannoudji of the École Normale Supérieure in Paris.

Now, researchers have succeeded in creating two- and three-dimensional arrays of atoms held in place by intersecting beams of laser light. Grynberg and his coworkers used three carefully positioned laser beams to create a two-dimensional, repeating hexagonal pattern of quantum traps. They then nudged cold cesium atoms into some of these light cages. They used four laser beams to create a three-dimensional optical crystal. In this case, the atoms occupied positions at the corners and in the center of each unit in a cubic lattice. This optical crystal held together for about a second before the atoms drifted out of position.

In a separate study, T.W. Hänsch and A. Hemmerich of the University of Munich in Germany prepared a two-dimensional optical crystal using cold rubidium atoms. These atoms occupied positions in a square grid established by two crossed, standing waves of laser light.

In both the French and German experiments, researchers saw evidence that the confined atoms vibrated at well-defined frequencies. "We have a situation in which the motion of the atoms located in the wells is purely quantum," Grynberg says.

Grynberg and Hemmerich described the results of their studies in separate presentations at the Quantum Electronics and Laser Science Conference held last week in Baltimore.

In general, most of the sites available in these optical crystals remain vacant. Grynberg reports that only one site in 10 is occupied by a cold atom. Even fewer sites – only one in 100 – are filled in the optical crystals assembled by the German group.

"The physics describing such a sample resembles that of an ultracold and very dilute solid," Hänsch and Hemmerich note.

Both groups are interested in increasing the number of atoms packed into their optical crystals. This means finding an alternative method of laser cooling and trapping that will accommodate a larger number of atoms than is now possible. Achieving higher densities would allow researchers to explore additional features of this new form of matter. For example, they could study situations in which two or more atoms occupy the same microscopic quantum well. They could also investigate how the interactions between confined atoms and light change as the number of atoms increases.

– I. Peterson