The Mott insulator

The cold-atom lattices studied in the Harvard and Max Planck experiments can be described by the Bose–Hubbard model. According to that model, atoms are governed by only two parameters: the interaction U when two atoms occupy the same site and the strength of tunneling J between lattice sites. The experimenters can control J and hence the ratio U/J by changing the depth of the potential wells in the optical lattice. When the ratio is low as in the superfluid phase, hopping is prevalent. As the ratio increases, atoms are pinned more strongly by the lattice and the system transitions to an MI, with the atoms essentially frozen in place. The recent experiments explored that transition. Although their findings yielded few surprises, "Still they are amazing to see," commented Pierre Meystre at the University of Arizona. "The pictures are gorgeous."

The images in figure 2, taken by the Harvard microscope, show a small region of a quantum gas in both the BEC and the MI phases. Shown are both the direct images and the result of an algorithm that determines which of the 10 × 8 lattice sites are occupied. Because atoms in a BEC freely hop from one site to another, they are delocalized across the entire lattice. On each site then it is equally likely to find an even or an odd number of atoms, hence the average measured site parity p is about 0.5. In the MI phase shown, atoms are fixed in place with all the sites singly occupied, so that p approaches 1 or 0.

Wider fields of view, such as the reconstructed images in figure 3, reveal the shell structure predicted for the MI. Theory predicts that as more atoms are added to the MI, the energy to put an atom in a lattice site outside a certain radius exceeds that for adding a second atom to the inner core. The resulting shell, or wedding cake, structure had been seen before[6–8] but never quite so visually.

The radial atom-number distribution within the observed shells is plotted in figure 3 for the BEC and the two MI phases shown in the top panel. As expected, p is approximately 0.5 for a BEC and approaches either 0 or 1 within an MI region. Also shown is the variance in those number distributions. The BEC is characterized by large fluctuations because atoms are free to hop from site to site. Large fluctuations also show up in relatively narrow regions just outside each MI shell. The low fluctuations in the MI regions indicate that the entropy is close to zero there: Those regions have dumped their entropy into the surrounding shells.

If the images from the Harvard and Max Planck groups offer any surprise, it is the sharpness of the transition region—both in space and in time—between the MI and the superfluid BEC. Spatially, some MI regions are only a few lattice sites wide. Temporally, the system is found to go from a BEC to an MI phase in a few milliseconds. Greiner is amazed that the atoms can arrange themselves so quickly, exactly filling all the right lattice sites.

The transfer of entropy out of the MI regions has given a number of experimenters an idea for further cooling. As explained by Greiner, ejecting those atoms just outside a core MI region can get rid of all that entropy. The new cooling regime might then reach the low enough temperatures for experiments on quantum spin systems.

In addition to trying to get to lower temperatures, the experimenters are working to extend their imaging capabilities to 3D. They are also exploring ways to manipulate the atoms, especially for applications to quantum computing.

Barbara Goss Levi

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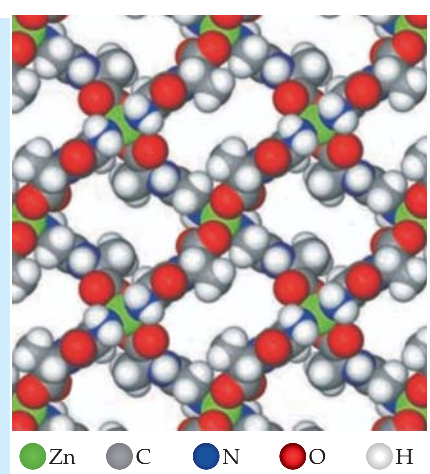
physics update

These items, with supplementary material, first appeared at http://www.physicstoday.org.

An expandable molecular sponge. Zinc ions and some other metal ions can bind to three or four organic molecules at once. If those molecules are long and attach to zinc at both ends, it's possible to create a metal–organic framework (MOF), an open sheet of linked molecules with ions at the vertices. And if those sheets bind to each other and stack in register, the result is a material whose columnar pores can store, catalyze, or otherwise usefully process small molecules. Matthew Rosseinsky and his coworkers at the University of Liverpool in the UK have made a MOF material, but with a new twist. For its linker, the Liverpool team used a dipeptide—that is, two peptide-bonded amino acids (glycine and alanine; see figure). The team made two versions of the material, one incorporating a solvent (a mix of water and methanol) and one not. X-ray diffraction and nuclear magnetic resonance spectroscopy revealed that adding the solvent caused the dipeptide linkers to straighten, widening the pores to accommodate the solvent ions. Glycine, alanine, and the 18 other naturally occurring amino acids are characterized by side chains that are polar, nonpolar, positively charged, or negatively charged. Given that variety, the Liverpool experiment suggests that peptide-based MOF materials might find uses as expandable sponges for a wide range of molecules. (J. Rabone et al., *Science* **329**, 1053, 2010.) —CD



Color-dependent cyclone activity. Under the hot summer sun, the ocean's surface waters become warmer than the atmosphere above them. As the heat is transferred to the atmosphere, it can strengthen low-pressure disturbances and drive the characteris-