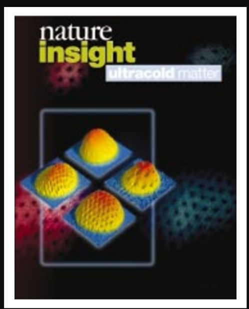
nature insight

Ultracold matter



Cover illustration
Quantum vortices in a rotating condensate of sodium atoms. The images represent two-dimensional cuts through the density distribution and show density minima attributable to the vortex cores. (Courtesy of J. R. Abo-Shaeer, MIT.)

Under unimaginably cold conditions, new types of physical behaviour await our discovery. As the thermal motions of atoms and molecules become progressively smaller, the elusive quantum world — usually masked at higher temperatures — should come into focus.

Superfluidity of liquid helium, first observed in the 1930s, is one of the earliest and most tangible examples. Although this phenomenon occurs at just 2 K, modern laser-cooling technology can attain much lower temperatures. So what happens when we skim absolute zero?

For atomic gases, this question was answered dramatically in 1995 with the production of a quantum state of matter known as a Bose–Einstein condensate. Formed at nanokelvin temperatures, a condensate is a cloud of atoms that pays no heed to everyday physical rules; atomic identities are lost as the particles blur into a coherent quantum entity.

Condensates and superfluids are inextricably linked, yet many questions surround their relationship. The main difference between atomic gas condensates and superfluid helium lies in the strength of the particle interactions, which are much weaker in the former system. This simplifying feature of Bose–Einstein condensates makes them extremely attractive for theoretical studies.

A source of coherent atoms also provides a wonderful practical tool. Just as the development of the laser revolutionized optics, so the ability to generate coherent matter waves opens exciting research possibilities. Nonlinear optical processes such as four-wave mixing can now be carried out using atoms in place of photons; matter-wave amplification has been observed, and atomic analogues of optical 'squeezed' states realized.

Although Bose–Einstein condensation is one of the triumphs of laser-cooling technology, it is by no means the only success story. Individual ultracold atoms and ions are also enormously versatile, making an impact in fields such as metrology and quantum information processing.

This collection of review articles covers some of the highlights of recent research into ultracold matter — a field that has seen two Nobel prizes within the past five years.

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