PERSPECTIVES: BOSE-EINSTEIN CONDENSATION

A New Trick of the Trade

Massimo Inguscio

Bose-Einstein condensation (BEC) is one of the most intriguing phenomena one can observe in physical systems. It is achieved by cooling a sample of atoms to nanokelvin temperatures and thereby trapping them in a single macroscopic quantum state. In the microscopic world of atoms, quantum mechanics rules the waves, yet, when Bose-Einstein condensation takes place, the atoms in the condensate share the same wave function, giving rise to a macroscopic quantum effect. Wave-mechanical properties of the atoms are then enhanced to an extent at which they can be observed and manipulated directly.

Enhanced online at www.sciencemag.org/cgi/content/full/292/5516/452

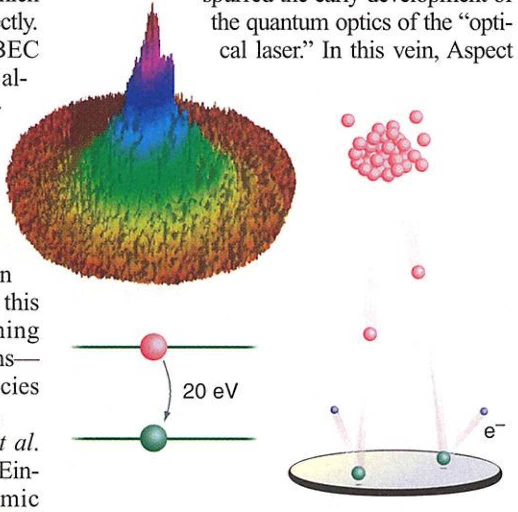
Since its first demonstration (*1*), BEC has been observed (*2*) in dilute gases of alkali atoms and in hydrogen. A wide variety of fascinating phenomena, including interference and amplification of coherent matter waves, atom "lasers" (*3*), nonlinear matter wave optics, collective excitations and oscillations, and superfluidity, have been observed in Bose-Einstein condensates. But to date, this plentiful phenomenology—all stemming from a bunch of ultracold trapped atoms—has only been reported for atomic species confined to their electronic ground state.

On page 461 of this issue, Robert *et al.* (*4*) report the first realization of a Bose-Einstein condensate in a metastable atomic state. They use helium atoms for their experiments. BEC occurs in a state with quite a high internal energy (about 20 eV) with respect to the ground state. This energy can easily be released through collisions with other atoms or a surface. The authors exploit this singular feature to perform a time-resolved detection of Bose-Einstein condensed atoms as they fall with different times on a microchannel plate after having been released from a trap (see the figure).

Several groups are searching for BEC in an excited or metastable state. Ionizing collisions, through which the excited atoms quickly release their internal energy, have been a major hindrance. According to model predictions (*5*), spin-polarized gases such as those used in the process of condensation were expected to inhibit such collisions, but it remained unclear whether this inhibition would be large enough to trigger condensation.

The author is in the Department of Physics, European Laboratory for Non-Linear Spectroscopy, University of Florence, Florence, Italy. E-mail: inguscio@lens.unifi.it

The achievement of BEC in metastable helium (*4*) demonstrates that the inhibition can be sufficiently strong. It thus paves the way for a new set of investigations. Unlike condensate detection schemes based on optical imaging, sensitive time-resolved detection of the condensate evolution will enable the study of statistical properties associated with quite large numbers of atoms and may also allow the detection of a few atoms within the condensate. Single-atom counting for condensates may be just within reach and would lead to a deeper understanding of the "atom laser" in much the same way as photocounting techniques spurred the early development of the quantum optics of the "optical laser." In this vein, Aspect and co-workers plan to carry out quantum atom-optics experiments analogous to the experiments that were milestones in the development of quantum optics. The Bose-Einstein condensation of ^{4}He could also open new directions in the investigation of fermionic ^{3}He sympathetically cooled by the collisions between the two species. In this case, the possibility of counting fermions in a metastable state could lead to a more favorable scenario with respect to the one for atoms in the ground-state as in, for instance, the ^{6}Li/^{7}Li mixtures (*6*).



A new detection scheme. Helium atoms from the condensate (**top**) fall and impinge on a microchannel plate, releasing their large internal energy (20 eV) to electrons that provide the detection signal.

Shortly after the experiments by Roberts *et al.* were submitted to *Science*, BEC of metastable helium was achieved by Cohen-Tannoudji and Leduc and co-workers (*7*). The two experiments mainly differ in their detection methods and complement each other with regard to the measurement precision and information they convey. From the size of the condensate, Pereira *et al.* (*7*) infer a scattering length that is consistent with the value of Roberts *et al.* (*4*); this value turns out to be rather high, four to five times higher than that of the original ^{87}Rb condensate. In a normal atomic gas, the separation between atoms is much larger than the effective size of the atoms, which is characterized by the scattering length. Large values of the scattering length in a Bose-Einstein condensed gas thus imply many collisions during one single oscillation of the condensate in the trap. Large scattering lengths have also been reported in ^{85}Rb (*8*). These experiments used a magnetic field–induced resonance that moves the condensate from a regime of positive to negative scattering length.

It will now be important to explore phenomena associated with large values of the scattering length in helium condensates rather than in other condensates whose lifetime is simply not long enough to make such an investigation possible (*8*). In the hydrodynamic regime in which the scattering length may become so large as to compare with the interatomic distance, it should be possible to observe effects that go beyond the mean field theory, for example, effects associated with condensate quantum depletion (*9*). In this new regime, frequency shifts in the collective oscillations of the condensate (*10*) or even intriguing changes in the critical temperature for condensation may become observable (*11*). Helium has a further important advantage for BEC studies. Because it is a relatively simple system that enables quasi-exact calculations, the ready availability of ultracold helium samples is expected to open new perspectives toward testing fundamental laws of physics (*12*).

What started out as a subfield of laser cooling and atomic physics has become the workhorse of a rapidly growing field that continues to contribute to major areas of physics. The condensation in metastable helium is another important achievement, which the BEC community will receive with delight.

References and Notes

1. M. A. Anderson *et al., Science* **269**, 198 (1995).
2. M. Inguscio, S. Stringari, C. Wieman, Eds., *Proceedings of the International School of Physics "E. Fermi," Course CXL* (IOS Press, Amsterdam, 1999).
3. S. Martellucci *et al.*, Eds., *Bose-Einstein Condensates and Atom Lasers* (Kluwer/Plenum Press, New York, 2000).
4. A. Robert *et al., Science* **292**, 461 (2001); published online 22 March 2001 (10.1126/science.1060622).
5. G. V. Shlyapnikov *et al., Phys. Rev. Lett.* **73**, 3247 (1993).
6. See K. M. O'Hara and J. E. Thomas, *Science* **291**, 2556 (2001) for a review of the recent developments in the field of sympathetic cooling.
7. F. Pereira Dos Santos *et al., Phys. Rev. Lett.*, **86**, 3459 (2001); see also http://xxx.lanl.gov/abs/cond-mat/0103387.
8. J. L. Robert *et al., Phys. Rev. Lett.* **85**, 728 (2000).
9. F. Dalfovo *et al., Rev. Mod. Phys.* **71**, 463 (1999).
10. D. M. Stamper-Kurn *et al., Phys. Rev. Lett.* **81**, 500 (1998).
11. C. Cohen-Tannoudji, S. Stringari, personal communication.
12. F. Minardi *et al., Phys. Rev. Lett.* **82**, 1112 (1999).