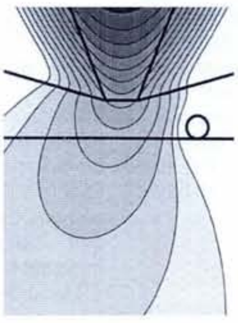

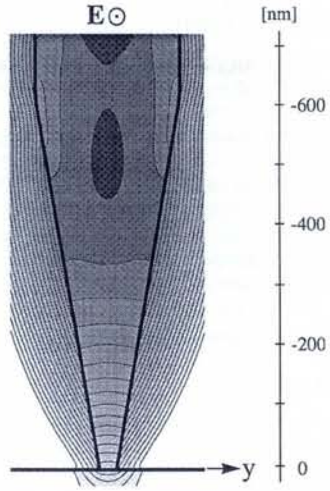

Fig. 5 - Modelling of SNOM image generation.
A; left) two-dimensional, 30 nm wide (slit) aperture scanned across a 20 nm in diameter wire. Contours give the calculated electrical energy density. They are severely disturbed when the object passes across the slit. From [7].
B; right) three-dimensional, aluminium-coated pointed glass-fibre tip. Contours giving the calculated flux of light along the path to the tip apex show a strong decrease in intensity on approaching the apex (x-direction parallel to the plane of polarization; factor of three between successive contour lines).

for both amplitude and phase contrast has reached a reasonably advanced level of maturity. But to achieve its ultimate resolution, possibly in the 1-3 nm range, it will be necessary to invent new near-field optical probes differing considerably from the ones employed up to now.

ACKNOWLEDGMENTS

The development of "forbidden light" microscopy at IBM Rüschlikon is the result of an extensive collaboration between experimentalists and theoreticians. The author should like to thank, in particular, A. Dereux, B Hecht, H. Heinzelmann, and L. Novotny for their dedicated work and essential contributions.

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BOSE-EINSTEIN CONDENSATION

A Fascinating Period Lies Ahead

J.T.M. Walraven from the Van der Waals - Zeeman Institute, Amsterdam University, discusses the implications of recent observations of Bose-Einstein condensation in alkali metal gases.

A very exciting recent experiment by Eric Cornell and Carl Wieman at JILA (Boulder, CO, USA) marks the beginning of a new chapter in the history of degenerate quantum systems. In early June, the JILA group observed Bose-Einstein condensation (BEC) in an ultra-cold gas of ^{87}Rb atoms, and started the first experiments on a degenerate atomic Bose gas [see M.H. Anderson M.H. *et al., Science* **269** (1995) 198]. More recently, BEC has been announced for ^{7}Li by Randall Hulet at Rice University, USA. Other systems are likely to follow in the near future.

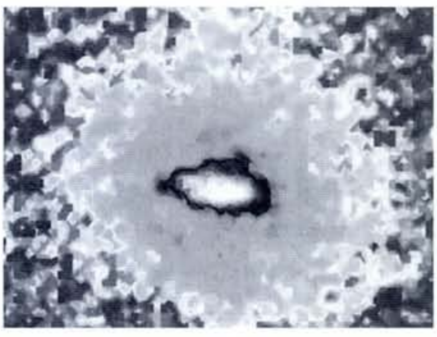
Unlike liquid helium, the only degenerate boson fluid thus far investigated, the dilute Bose gases are weakly interacting. This allows for large condensate fractions and an exceptionally transparent physical picture of many-body quantum behaviour. Not surprisingly, the quantum gases have intrigued and inspired physicists throughout this century. In the absence of experimental examples, their importance as theoretical model systems gave rise to a whole literature on "fictitious" ideal or nearly ideal degenerate quantum gases, both Bose and Fermi systems. In these studies, the dilute boson gas was invaluable for the development of the microscopic theory of superfluidity, starting from first principles with the binary collision approximation at temperatures where only s-wave scattering is assumed to contribute.

Search Culminated

The recent experiment at JILA forms the culmination point of a research programme in which two important principles from earlier experiments with ultra-cold atomic gases were successfully combined, namely (a) trapping by laser cooling methods with optical investigation of the samples, and (b) evaporative cooling of magnetically trapped samples to achieve BEC. Laser cooling proved extremely powerful to trap a variety of ultra-cold atoms with easily accessible optical transitions, in particular alkali atoms. Sensitive and convenient optical detection methods were developed, capable of imaging even a small number of atoms. However, optical cooling methods appear to be less suited to obtaining BEC because several light-related phenomena tend to limit achievable densities and temperatures to values far from those required for BEC. Evaporative cooling involves the preferential removal of the most energetic atoms from a sample and was developed with the aim of achieving BEC in spin-polarized atomic hydrogen, the first quantum gas to be studied experimentally. Although many properties of non-degenerate quantum gases have been investigated with hydrogen, in this system the progress towards BEC is slowed down by the lack of good diagnostics.

Exciting Prospects

There are several aspects that make the JILA experiment significant beyond the mere observation of BEC. Unlike liquid helium, the trapped atomic gases are inhomogeneous. This gives rise to an unique and almost complete spatial separation between the condensate and above-condensate particles. The separation manifests itself in one of the most exciting features of the JILA experiment. Once the condensate has formed, the above-condensate particles can be removed "mechanically" using a radiofrequency-based technique, enabling almost instant cooling to immeasurably low temperatures and leaving an essentially pure condensate which could be observed for about 15 s. The inhomogeneity also allows the investigation of interaction-related phenomena in spite of the fact that the samples are extremely



An image of the velocity distribution of a cloud of cooled and trapped Rb atoms that have formed a Bose-Einstein condensate. The high-density central (light contrasting) region is elliptical indicating that it has a highly nonthermal distribution (it is in fact an image of a single macroscopically occupied quantum wave function). Andersen M.H. et al., Science ***269*** *(1995) 199, with permission*

Bose-Einstein Condensation

Atoms are normally considered as particles but, according to quantum mechanics, they also have wave-like properties. Indeed, an atom has an equivalent wavelength, the deBroglie wavelength, which is inversely proportional to the atom's momentum. As atoms are cooled they slow down and their deBroglie wavelength increases. Satyendra Bose and Albert Einstein predicted 70 years ago that at a low enough temperature the wavelength exceeds the inter-particle spacing and the atoms begin to overlap. The atoms become indistinguishable, effectively entering - by a process called Bose-Einstein condensation (BEC) - a coherent state where the laws of quantum mechanics govern the behaviour of the macroscopic system. BEC has been observed in superfluid helium-4 and superconductivity, both being states of matter in which bosons (integral-spin particles) condense into macroscopic quantum states. But the bosons in these systems interact with each other, so to better understand BEC, physicists have tried for sometime to bring about condensation in an ideal gas of noninteracting atoms.

The JILA Experiment

The JILA experiment consists of three stages: A - optical loading, (pre)cooling & polarization; B - magnetic trapping & evaporative cooling in the absence of light; C - optical detection.

A - laser cooling stage. For 300 s, about 10^7 atoms are gathered from the low-velocity tail of a room-temperature Rb-vapour at some 10^{-11} mbar into a so-called "dark" magneto-optical trap (MOT), which is most efficient in collecting a large number of atoms by optical forces. The gas is rapidly (pre)cooled in the MOT to about 20 μK and subsequently magnetically polarized in a small magnetic bias field by optical pumping.

B - trapping and cooling. Polarized atoms are magnetically trapped in a rapidly applied time-orbiting potential (TOP) trap, which consists of a set of coils in anti-Helmholtz configuration with a small, uniform transverse field, rotating at 7.5 kHz, superimposed. The TOP provides an effectively harmonic potential with an axial frequency of about 120 Hz and radial frequency of about 42 Hz. In the TOP, the gas is adiabatically compressed to reach the starting conditions for evaporative cooling at about 90 μK with a number density of about 2×10^{10} cm^{-3}, sufficiently large to have the elastic collision rate dominate over the loss rate in the gas. The evaporation takes 70 s and BEC is achieved with 2×10^4 atoms at approximately 170 nK. The evaporation is induced by a RF transition to an untrapped state of the atoms at the edge of the sample.

C - optical detection. At the start of the detection stage the trap is expanded adiabatically to a larger size to allow a fast (destructive) absorption measurement in which the sample is imaged on a CCD camera. The appearance of a diffraction ring marks the growth of a partially resolved structure in the sample. This is consistent with BEC in an inhomogeneous sample, where the condensate is expected to appear as a very small, dense gas cloud at the centre of the potential well. To confirm this interpretation, the momentum distribution in the sample was measured by suddenly switching-off the trap and observing the expanding gas cloud. In this process both isotropic expansion of the (thermal) non-condensate fraction was observed as well as an anisotropic expansion, as is to be expected for a suddenly released anisotropic single quantum state.

dilute, with only a few collisions per atom per second. Since, in the absence of interactions, the compressibility of a Bose condensate is infinite, the condensate will be compressed by the trapping potential until the interatomic interactions counter-balance the potential, thus affecting the size and shape of the condensate. This effect has also been observed at JILA (see figure).

Many intriguing problems await experimental investigation. Most prominent among them are the relation between BEC and superfluidity, the kinetics of BEC, the size and number dependence of the transition, optical properties, dimensionality aspects, the interaction between two condensates, the use of the condensate as a source for a coherent atomic beam, and the differences with respect to Fermi systems. One controversial topic — the stability of condensates under an attractive mean field (negative scattering amplitude) — is already being addressed by Randall Hulet, who observed diffraction rings indicating an internal structure in ultra-cold samples of ^{7}Li. Similar experiments can be done with ^{85}Rb. There are suggestions that the scattering amplitude of the heavy alkalis can be modified and its sign possibly even changed. Clearly, an exciting period lies ahead. It is fortunate that the results obtained by the group of Cornell and Wieman were realized with methods accessible to many groups in university environments as this will allow a wide exploration of the fascinating Bose-Einstein condensates.

INELASTIC X-RAY SCATTERING

Great Potential Demonstrated

F. Sette and G. Ruocco describe why the confirmation, at the European Synchrotron Radiation Facility, of fast sound in water at momentum transfers of from 4 to 14 nm^{-1} using inelastic X-ray scattering with a resolution in the meV range demonstrates the technique's important capabilities.

The determination of the collective dynamics in liquid water is a long-standing problem which dates back to 1974, when Rahman and Stillinger [1] proposed the existence of high-frequency collective excitations (so-called fast sound) propagating with a velocity which is much higher than that of ordinary sound. The proposal stimulated various studies, justified not only by the practical importance of liquid-like water but also by the implications associated with the possible coexistence of different kinds of acoustic-like excitations in molecular liquids.

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The first experimental verification came in 1985 from Texeira, Bellissent-Funel, Chen and Dorner (TBCD) [2], who performed inelastic neutron scattering experiments in heavy water at momentum transfer (q)-values of 3.5-6.0 nm^{-1}. Their results revealed strong evidence for collective excitations propagating with a speed of sound of 3300 ms^{-1}, a value that is two times larger than the velocity of ordinary sound in water. It was speculated at the time that this fast mode may propagate *via* the network of hydrogen bonds.

Since then, many theoretical analyses and molecular dynamics simulations have tried to clarify the origin of these excitations [3-5]. Despite these efforts, the issue could not be settled, mainly because neutron data were only available for a limited region of momentum transfer - frequency (q-ω) space. Moreover, in 1995 Bermejo *et al.* [6] made new neutron scattering measurements and claimed that there was no fast sound in heavy water.

Inelastic Scattering at the ESRF

The dynamical structure factor in liquid water has recently been determined by inelastic X-ray scattering at a total energy resolution of 3.2 meV using a newly constructed instrument at the European Synchrotron Radiation Facility, Grenoble. This technique, besides offering the possibility to investigate a much larger q-ω region than for neutrons, presents other important advantages with respect to neutrons for the specific problem of sound propagation in water. They are: a) the absence of an incoherent contribution to scattering spectra; and b) the possibility to study normal (as opposed to heavy) water using direct measurements.

The new results strongly favour theoretical models for the dynamics of water which account for fast sound in terms of an anomalously large increase at high frequencies of the speed of propagation of collective acoustic-like excitations [4, 5]. The physical origin of this increase lies mostly in the interplay between the different contributions to the intermolecular potential, *i.e.*, the different roles played by electrostatic and Lennard-Jones-like terms in determining the