New light on Bose-Einstein condensates

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We have studied and manipulated Bose-Einstein condensates with laser light. This includes the study of the optical properties of a condensate, matter-wave amplification by a condensate dressed by a pump laser beam, and studies of superfluidity. Light scattering imparts momentum to the condensate and creates an excitation. Consequently, the coherence and collective nature of excitations in the condensate can strongly affect the optical properties. The MIT group studied light scattering from a condensate in three different regimes:

(1) When light was scattered at large angles, the large momentum transfer led to atoms "popping out" of the condensate. The narrow resonance for this process showed a Doppler broadening due to the zero-point motion of the condensate and a line shift due to interactions within the condensate. The Doppler broadening was found to be the minimum one compatible with Heisenberg's uncertainty relation. This shows that the coherence length of a condensate is equal to its physical size [1].

(2) When the recoil momentum due to the light scattering (divided by the atomic mass) was less than the speed of sound in the condensate, light scattering was observed to be dramatically reduced. In this regime, where atoms cannot absorb momentum "individually" but only collectively, the suppression arises from destructive interference of two excitation paths. The suppression provides dramatic evidence for the presence of correlated momentum excitations in the many-body condensate wavefunction [2].

(3) At higher laser intensity, it was discovered that the light was not scattered randomly, but emitted along the axial direction of the elongated condensate. When a condensate has scattered light, an imprint is left in the form of long-lived excitations. This "memory" accelerates the scattering of further photons into the same directions. It provides a gain mechanism for the generation of directed beams of atoms and light [3]. When the superradiant condensate was seeded with recoiling atoms, these input atoms were amplified. We have characterized the amplification process and could demonstrate its phase-coherence by interfering the amplified beam with a reference beam. Such coherent matter-wave amplification can be used in active atom interferometers [4]. The superfluid and dissipative behavior of the condensate was probed with both macroscopic and microscopic probes. The macroscopic probe was a focused far-off-resonant laser beam which was stirred through the condensate. Strong dissipation was observed only above a critical velocity which was about four times smaller than the speed of sound [5]. Impurity atoms served as a microscopic probe. Impurity atoms propagating at variable velocities through a trapped Bose-Einstein condensate were produced using a stimulated Raman transition. The redistribution of momentum by collisions between the impurity atoms and the

stationary condensate was observed in a time-of-flight analysis. The collisional cross section was dramatically reduced when the velocity of the impurities was reduced below the speed of sound of the condensate, in agreement with the Landau criterion for superfluidity. For large numbers of impurity atoms, we observed an enhancement of atomic collisions due to bosonic stimulation. This enhancement is analogous to optical superradiance [6].

I acknowledge the contributions of my collaborators listed in the references below.

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