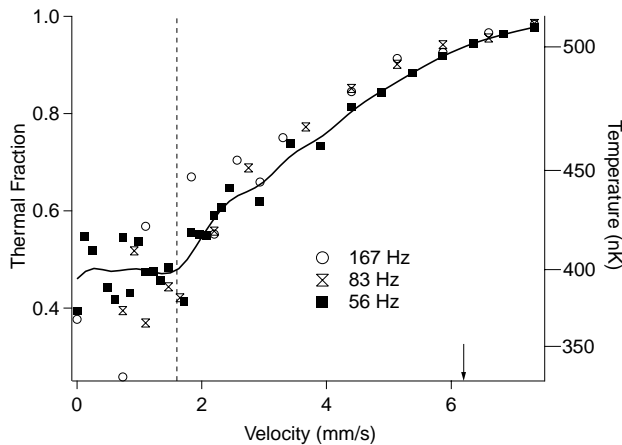


Evidence for a critical velocity in a Bose-Einstein condensate

The existence of a macroscopic order parameter implies superfluidity of gaseous condensates. Observing frictionless flow is a challenge given the small size of the system and its metastability. We have taken a step towards this goal by studying dissipation when an object was moved through the condensate [1]. This is in direct analogy with the well-known argument by Landau [2] and the vibrating wire experiments in superfluid helium [3]. Instead of dragging a massive macroscopic object through the condensate we used a blue detuned laser beam which repelled atoms from its focus to create a moving boundary condition.



Evidence for a critical velocity. Shown is the final temperature after a laser beam was scanned through the condensate at variable velocity for 900 ms using different scan frequencies. The dashed line separates the regimes of low and high dissipation. The peak sound velocity is marked by an arrow. The data series for 83 and 167 Hz showed large shot-to-shot fluctuations at velocities below 2 mm/sec. The solid line is a smoothing spline fit to the 56 Hz data set to guide the eye.

The beam created a “hole” with a diameter of 13 μm which was scanned back and forth along the long axis of the cigar-shaped condensate (Thomas-Fermi diameters of 45 and 150 μm in the radial and axial directions, respectively). After exposing the condensate to the scanning laser beam for about one second, the final temperature was determined. As a function of the velocity of the scanning beam, we could distinguish two regimes of heating separated by a critical velocity. For low velocities, no or little dissipation was observed, and the condensate appeared immune to the presence of the scanning laser beam. For higher velocities, the heating increased, until at a velocity of about 6 mm/s the condensate was almost completely depleted after the stirring. The cross-over between these two regimes was quite pronounced and occurred at a velocity of about 1.6 mm/s which was a factor of roughly four smaller than the speed of sound at the peak density of the condensate (see figure).

These observations are in qualitative agreement with numerical calculations based on the non-linear Schrödinger equation which predict that heating at subsonic velocities is due to the onset of vortex nucleation [4-6]. Because of surface effects and the non-zero temperature, we expect additional corrections leading to dissipation at even lower velocities and a smooth crossover between low and high dissipation. More precise measurements of the heating should allow us to study these finite-size and finite-temperature effects.

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