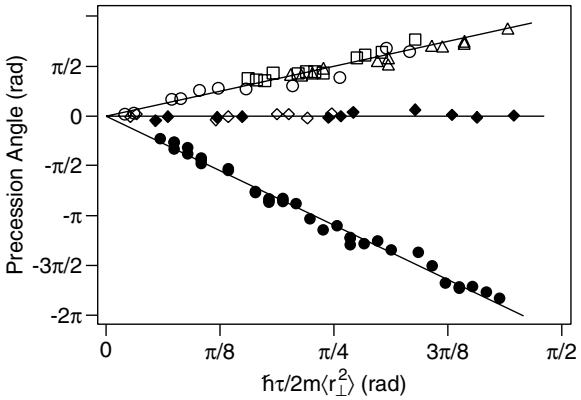
Topological vortex formation in a Bose-Einstein condensate

Following the theoretical suggestion [1], we have demonstrated a new method to create vortices in Bose-Einstein condensates. Vortices were imprinted into the condensate wavefunction using topological phases. Sodium condensates held in an Ioffe-Pritchard magnetic trap were transformed from a non-rotating state to one with quantized circulation by adiabatically inverting the magnetic bias field along the trap axis [2]. During this process, the magnetic fields rotated around position-dependent axes, and the associated Berry's phase resulted in a vortex singularity.

Using surface wave spectroscopy, the axial angular momentum per particle of the vortex states was found to be consistent with $2\hbar$ or $4\hbar$, depending on the hyperfine state of the condensate.



Surface wave spectroscopy. A quadrupolar deformation precessed with the rotating condensate. The graph shows the precession angle vs. normalized time in the presence of a vortex for condensates in the |1, -1> state measured after a delay of 0 ms (open circles), 5 ms (open squares), and 20 ms (open triangles) from the completion of the inversion of the axial bias field, in the absence of a vortex for |1, -1> (open diamonds) and |2, 2> (filled diamonds) condensates, and in the presence of a vortex for |2, 2> condensates measured immediately upon the completion of the inversion of the axial bias field (filled circles).

1. T. Isoshima, M. Nakahara, T. Ohmi, and K. Machida, *Creation of a persistent current and vortex in a Bose-Einstein condensate of alkali-metal atoms*, Phys. Rev. A **61**, 063610 (2000).
2. A.E. Leanhardt, A. Görlitz, A.P. Chikkatur, D. Kielpinski, Y. Shin, D.E. Pritchard, and W. Ketterle, *Imprinting vortices in a Bose-Einstein condensate using topological phases*, Phys. Rev. Lett. **89**, 190403 (2002).