Observation of Vortex Lattices in Bose-Einstein Condensates

Quantized vortices play a key role in superfluidity and superconductivity. In superconductors, magnetic flux lines arrange themselves in regular lattices that have been directly imaged. In superfluids, direct observation of vortices had been limited to small arrays (up to 11 vortices), both in liquid $^4$He [1] and more recently in rotating gaseous Bose-Einstein condensates (BEC) [2, 3].

We have observed the formation of highly-ordered vortex lattices in a rotating Bose-condensed gas [4]. They were produced by rotating the condensate around its long axis using the optical dipole force exerted by a blue-detuned laser. A striking feature of the observed lattices is the extreme regularity, free of any major distortions, even near the boundary. Such “Abrikosov” lattices were first predicted for quantized magnetic flux lines in type-II superconductors. The observed triangular lattices contained over 100 vortices with lifetimes of several seconds. Individual vortices persisted up to 40 s. The lattices could be generated over a wide range of rotation frequencies and trap geometries, shedding light on the formation process. Our observation of lattice dislocations, irregular structure and dynamics indicate that gaseous Bose-Einstein condensates may be a model system for the study of vortex matter.

Observation of vortex lattices. The examples shown contain (A) 16 (B) 32 (C) 80 and (D) 130 vortices. The vortices have "crystallized" in a triangular pattern. The diameter of the cloud in (D) was 1 mm after ballistic expansion which represents a magnification of 20.