Observation of the Berezinskii-Kosterlitz-Thouless transition in a photonic lattice

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Abstract:

Phase transitions give crucial insight into many-body systems, as the crossover between different regimes of order are determined by the underlying interactions. These interactions, in turn, are often constrained by dimensionality and geometry. For example, in one- and two-dimensional systems with continuous symmetry, thermal fluctuations prevent the formation of long-range order. Two-dimensional systems are particularly significant, as vortices can form in the plane but cannot tilt out of it. At high temperatures, random motion of these vortices destroys large-scale coherence. At low temperatures, vortices with opposite spin can pair together, cancelling their circulation and allowing quasi-long-range order to appear. This Berezenskii-Kosterlitz-Thouless (BKT) transition is essentially classical, arising for example in the traditional XY model for spins, but to date experimental evidence has been obtained only in cold quantum systems. Measurements of superfluid sound speed and critical velocity have been consistent with scaling predictions, and vortices have been observed directly in cold atom experiments. However, the presence of trapping potentials restricts measurement to vortex density, rather than number, and obscures the process of vortex unbinding. Further, atom and fluid experiments suffer from parasitic heating and difficulties in phase recording, leading to results that differ from theory in many quantitative aspects. Here, we use a nonlinear optical system to directly observe the ideal BKT transition, including vortex pair dynamics and the correlation properties of the wavefunction, for both attractive and repulsive interactions (the photonic equivalent of ferromagnetic and antiferromagnetic conditions). The results confirm the thermodynamics of the BKT transition while raising outstanding issues regarding the non-equilibrium approach to it.