Berezinskii-Kosterlitz-Thouless transitions in an easy-plane ferromagnetic superfluid

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In two-dimensional Bose gases thermal fluctuations preclude the formation of long-range order. Consequently, the superfluid transition is of the Berezinskii-Kosterlitz-Thouless (BKT) type, characterized by the emergence of quasi-long-range order driven by the binding of vortex-antivortex pairs. Spinor Bose gases provide a unique platform to study BKT transitions, on account of their ability to simultaneously exhibit phase and spin ordering. Here we utilize a stochastic Gross-Pitaevskii model to investigate the BKT transitions in an easy-plane ferromagnetic spin-1 Bose gas. We identify the mass/spin superfluid phase diagram as a function of quadratic Zeeman energy. Two BKT transitions occur with decreasing temperature: first mass superfluidity is established, followed at a lower temperature by spin superfluidity. We demonstrate that these transitions are associated with the binding of mass and spin vortex-antivortex pairs respectively. Above the spin BKT temperature, the component circulations that make up each spin vortex spatially separate, suggesting possible deconfinement analogous to quark deconfinement in high energy physics. Intercomponent interactions give rise to superfluid drag between the spin components, which we calculate analytically at zero temperature.

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