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Thermal fluctuations in two-dimensional dilute atomic gases

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A paramagnetic-ferromagnetic quantum phase transition is known to occur at zero temperature in a two-dimensional coherently-coupled Bose mixture of dilute ultracold atomic gases provided the interspecies interaction strength is large enough. Here we study the fate of such a transition at finite temperature by performing numerical simulations with the stochastic (projected) Gross-Pitaevskii formalism (SGPE), which includes both thermal and beyond mean-field effects. By extracting the average magnetization, the magnetic fluctuations and characteristic relaxation frequency (or, critical slowing down), we identify a finite temperature critical line for the transition. We find that the critical point shifts linearly with temperature and, in addition, the three quantities used to probe the transition exhibit a temperature power-law scaling. The scaling of the critical slowing down is found to be consistent with thermal critical exponents and is very well approximated by the square of the spin excitation gap at the zero-temperature. In the absence of coupling, we use a mean-field Hartree-Fock theory to derive analytical predictions for the miscible-immiscible transition. A nontrivial result of this theory is that a fully miscible phase at $T = 0$ may become unstable at $T \neq 0$, as a consequence of a divergent behaviour in the spin susceptibility. Using SGPE, we calculate the equilibrium configurations at different temperatures and interaction strengths and we simulate spin oscillations produced by a weak external perturbation. Despite some qualitative agreement, the comparison between the two theories shows that the mean-field approximation is not able to properly describe the behavior of the two-dimensional mixture near the miscible-immiscible transition, as thermal fluctuations smoothen all sharp features both in the phase diagram and in spin dynamics, except for temperature well below the critical temperature for superfluidity.

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