First-Order and Berezinskii-Kosterlitz-Thouless phase Transitions in two-dimensional generalized XY model

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In the 60s, Landau's paradigm, which states that all phase transitions involves a symmetry breaking, along with the Mermin-Wagner Theorem, which sayas that two dimensional systems with short-range interactions do not exhibit long-range order at finite temperature, defined the understanding of phase transitions. According to this, the two-dimensional XY model would not characterized by a power-law correlation function at low temperatures, becomes an exponential correlation function at high temperatures, indicating a new type of phase transitions involving the unbinding of topological objects know as vortices. This transition became know as the Berezinskii-Kosterlitz-Thouless(BKT) phase transition. Applications in superfluidity and superconductivity led to the 2016 Nobel Prize in Physics being awarded to Thouless and Kosterlitz. Motivated by this phase transition, various generalizations of models that support this type of transition have been proposed. Among them, Romano and Zagrebnov[1] proposed a generalizaiton of the XY model, where in the two-dimensional with an arbitrary generalized parameter q, the universality class of the transiiton may or may not correspond to that of the traditional BKT transition. Although intially debated, Van Enter et al.[2] provided rigorous proof that the 2D generalized XY model exhibits a first-order phase transition. However, the critical generalization parameter q and the critical temperature at which this transition occurs, as well as the mechanism behind the first order phase transition, remained open questions. To adddress these open questions, we applied two different approaches[3]. The first was through Monte Carlo method, where we obtained the system's thermodynamics. By using different parameters we determined the critical temperature for different values of q. Defining the vortex density as the order parameter, we were able to find the critical q parameter at which the first-order phase transition occurs. The second method involved extending the solutions obtained by Van Enter, where it was possible to derive the critical temperature and critical parameter which agreed with the simulations. We also demonstrated that there are three distinct regions classified by their phase transitions, and that the system undergoes a disordered-disordered first-order phase transition caused by the proliferation of vortices in the system.

References

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Type

ORAL