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Mean-field theory becomes exact under shear flow: A dynamic renormalization group study of the O(n) model

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Mean-field theory, such as Landau theory, provides a simple yet powerful framework for understanding critical phenomena. However, in equilibrium systems, its predictions often fail in low dimensions: the upper critical dimension is typically four, and significant deviations in critical exponents are observed in two and three dimensions. Intriguingly, experiments on phase separation under shear flow and recent simulations of spin models have reported mean-field-like critical exponents even in two dimensions [1, 2]. These findings suggest that shear flow may fundamentally alter the nature of critical behavior, effectively lowering the upper critical dimension. To uncover the physical mechanism behind this phenomenon, we performed a dynamic renormalization group analysis of the O(n) model under simple shear flow [3]. A key innovation of our work is the explicit treatment of shear-induced anisotropy in the scaling analysis—an aspect neglected in earlier studies [4]. Our results reveal the existence of a novel Gaussian fixed point governed by strong anisotropy due to shear. Strikingly, we find that the upper critical dimension of this fixed point is reduced to two or lower for both conserved and non-conserved dynamics. This implies that mean-field theory becomes asymptotically exact in all dimensions except one. [1] D. Beysens, M. Gbadamassi, and L. Boyer Light-Scattering of a Critical Mixture with Shear Flow, Phys.Rev.Lett. 43 (1979) 1253 [2] H. Nakano, Y. Minami, and S. Sasa Long-Range Phase Order in Two Dimensions under Shear Flow, Phys.Rev.Lett. 126 (2021) 1606 04 [3] H. Ikeda, and H. Nakano, Dynamical renormalization group analysis of O(n) model in steady shear flow, arXiv:2412.02111 (2024) [4] A. Onuki, and K. Kawasaki, Nonequilibrium Steady State of Critical Fluids under Shear Flow: A Renormalization Group Approach, Ann. Phys. 121 (1979) 456

Presenter: IKEDA, Harukuni