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Phonon renormalization and Pomeranchuk instability in the Holstein model

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The Holstein model with dispersionless Einstein phonons is one of the simplest models describing electron-phonon interactions in condensed matter. A naive extrapolation of perturbation theory in powers of the relevant dimensionless electron-phonon coupling suggests that at zero temperature the model exhibits a Pomeranchuk instability characterized by a divergent uniform compressibility at a critical value where the dimensionless electron-phonon coupling is of order unity. In this work, we re-examine this problem using modern functional renormalization group (RG) methods. For dimensions d > 3 we find that the RG flow of the Holstein model indeed exhibits a tricritical fixed point associated with a Pomeranchuk instability. This non-Gaussian fixed point is ultraviolet stable and is closely related to the well-known ultraviolet stable fixed point of phi^3-theory above six dimensions. To realize the Pomeranchuk critical point in the Holstein model at fixed density both the dimensionless electron-phonon coupling and the adiabatic ratio (phonon frequency divided by Fermi Energy) have to be fine-tuned to assume critical values of order unity. On the other hand, for dimensions d=3 or smaller we find that the RG flow of the Holstein model does not have any critical fixed points. This rules out a quantum critical point associated with a Pomeranchuk instability in d=3 or smaller.

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