Classical and quantum buckling transitions in cold ion crystals

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Crystals of repulsively interacting cold ions in planar traps form hexagonal lattices, which undergo a buckling instability towards a multi-layer structure as the transverse trap frequency is reduced. The buckled structure is composed of three planes, whose separation increases continuously from zero. In this work [1], we study the effects of thermal and quantum fluctuations by mapping this structural instability to the six-state clock model. A prominent implication of this mapping is that at finite temperature T, fluctuations split the buckling instability into two thermal transitions, accompanied by the appearance of an intermediate critical phase. This phase is characterized by quasi-long-range order in the spatial tripartite pattern. It is manifested by broadened Bragg peaks at new wave vectors, whose line-shape provides a direct measurement of the temperature dependent exponent $\eta(T)$ characteristic of the power-law correlations in the critical phase. A quantum phase transition is found at the largest value of the critical transverse frequency, where the critical intermediate phase shrinks to zero. Moreover, within the ordered phase, we predict a crossover from classical to quantum behavior, signifying the emergence of an additional characteristic scale for clock order. We discuss experimental realizations with trapped ions and polarized dipolar gases, and propose that within accessible technology, such experiments can provide a direct probe of the rich phase diagram of the quantum clock model, not easily observable in condensed matter analogues. This highlights the potential for ionic and dipolar systems to serve as simulators of complex models in statistical mechanics and quantum field theory.

[1] Daniel Podolsky, Efrat Shimshoni, Giovanna Morigi and Shmuel Fishman, Phys. Rev. X 6, 031025 (2016).