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Orientational melting of a two-dimensional ensemble of charged particles

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A system of confined charged particles undergoes crystallization at sufficiently low temperature, forming self-organized structures in which each particle is spatially localized. However, when particles in a two-dimensional plane are confined by an isotropic potential, there is no preferential orientation of the crystal, and thermal fluctuations lead to the delocalization of particles in circular trajectories. Following this orientational melting of the crystal, the particles remain localized radially and delocalized in the angular direction. Orientational melting of a mesoscopic crystal is a change of configuration that is similar to a phase transition in a macroscopic system, but it is not universal as it depends on the specific properties of the system, e.g. the exact number of particles.

We report on the experimental observation and characterization of orientational melting in a two-dimensional crystal of trapped Ba+ ions [1].

The specific geometry of our trap [2] makes it possible to continuously change the arrangement of the ions from a one-dimensional string to a two-dimensional crystal while keeping the ions always in a two-dimensional plane. We observe that orientational melting occurs under conditions that strongly depend on the number of particles, and find excellent agreement with the results of a Monte Carlo simulation, which we use to estimate the temperature of the ions at which melting occurs. Additionally, we are able to locally inhibit melting by adding a single impurity with a different mass. Interestingly, for a sufficiently large number of ions two or more concentric rings are populated, and the rings can exhibit independent dynamics.

Our experiment paves the way to accessing quantum regimes for delocalized strongly-interacting particles, and in particular for the coherent control of the rotational state of the ions [3] by entangling it to the ions' internal state.

[1] L. Duca, N. Mizukami, E. Perego, M. Inguscio, C. Sias, arXiv:2209.00395
[2] E. Perego, L. Duca, C. Sias, Appl. Sci. 10, 2222 (2020)
[3] E. Urban, et al. Phys. Rev. Lett. 123, 133202 (2019)

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