Supersolid-Like Square-Lattice Crystallization of Droplets in Dipolar Bose-Einstein Condensate

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A supersolid, or a superfluid solid, is a quantum state of matter simultaneously possessing the properties of both a solid and a superfluid. Hence, a supersolid has a spatially-periodic crystalline structure as a solid, breaking continuous translational invariance, and also enjoys frictionless flow like a superfluid, breaking continuous gauge invariance. The study of supersolids has recently gained new momentum among research workers in various fields, after the experimental observation of supersolids in a quasi-one-dimensional (quasi-1D) and quasi-two-dimensional (quasi-2D) dipolar Bose-Einstein condensate (BEC) and in a quasi-1D SO-coupled pseudo spin-1/2 spinor BEC.

In this work we study a supersolid-like spatially-periodic square-lattice crystallization of droplets, in addition to the commonly-studied triangular-lattice crystallization, in a cylindrically-symmetric quasi-two-dimensional trapped dipolar condensate, using an improved mean-field model including a quantum-fluctuation Lee-Huang-Yang (LHY) type interaction, meant to stop a collapse at high atom density. In that framework, as the number of atoms N in a trapped dipolar BEC is increased, so that the density of atoms reaches a critical value, due to the dipolar attraction, the condensate shrinks to a very small size. However, it cannot collapse due to the LHY interaction and a droplet is formed in the case of an appropriate mixture of contact and dipolar interactions. We show that these types (square- and triangular-lattice) of crystallization, and even a supersolid-like spatially-periodic honeycomb-lattice, of droplets may appear for the *same* atomic interaction and the *same* trap frequencies. As an important result, we demonstrate that the energy E of all three crystallization as a function of number N of atoms satisfy the universal scaling relation $E \sim N^{0.4}$ indicating that all three arrangements of the droplets should be energetically probable processes of phenomenological interest, whereby the results of this study can be tested experimentally with present knowhow.