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Collective modes of vortex lattices in two-component Bose-Einstein condensates under synthetic gauge fields

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概　要

There has been an ever-growing interest in artificially created gauge fields in ultracold atomic gases, which are induced by either rotating gases or optically dressing atoms. When the gas is composed of two ggcomponents, the former (latter) method induces mutually parallel (antiparallel) synthetic magnetic fields in the two components. Two-component Bose-Einstein condensates (BECs) in parallel and antiparallel fields are known to show the same vortex-lattice phase diagram with five different lattice structures determined by the ratio of the intercomponent interaction to the intracomponent one within the mean-field theory [1,2]. Therefore it is interesting to ask whether and in what way the difference between the cases of parallel and antiparallel fields occurs. Here we study collective modes of vortex lattices in two-component BECs by means of the Bogoliubov theory and an effective field theory [3]. We find that two modes with linear and quadratic dispersion relations appear in both the types of synthetic fields. We also analyze the anisotropy of the Bogoliubov excitation spectra at low energies and find that it is well described by the effective theory for all vortex lattice phases. While the excitation spectra are significantly different between the two types of synthetic fields, their low-energy parts are found to be related to each other by simple rescaling for intercomponent attraction. However, contrary to the effective theory prediction, this relation is violated for intercomponent repulsion with a greater degree of violation for larger repulsion. Apart from the low-energy features, the excitation spectra exhibit the band touching at high-symmetry points and along lines in the 1st Brillouin zone. We find that this band touching can be understood from "fractional" translational symmetry. However, we can not explain some features of the spectra at high-symmetry points from a symmetry viewpoint. We explain their origins on the basis of numerical data of the Bogoliubov Hamiltonian matrix.

[1] E. J. Mueller and T.-L. Ho, Phys. Rev. Lett **88**, 180403 (2002); K. Kasamatsu, M. Tsubota, and M. Ueda, Phys. Rev. Lett. **91**, 150406 (2003).

[2] S. Furukawa and M. Ueda, Phys. Rev. A **90**, 033602 (2014).

[3] T. Yoshino et al., New J. Phys. **21**, 015001 (2019).

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