Exploring phononlike interactions in one-dimensional Bose-Fermi mixtures

Axel Gagge[1], Themistoklis Mavrogordatos[1,2], and Jonas Larson[1]

[1]*Department of Physics, Stockholm University, SE-106 91 Stockholm, Sweden*
[2]*ICFO - The Institute of Photonic Sciences, Avinguda Carl Friedrich Gauss, 3, 08860 Castelldefels, Barcelona, Spain*

We investigate a cold atomic Bose-Fermi (BF) mixture confined in an optical lattice potential solely affecting the bosons with the objective of simulating the physical behavior of electrons in a dynamic background. We do so by assigning tractable degrees of freedom to the lattice, which renders its description dynamic and enables the simulation of some analog of phononlike interactions. In mixtures of bosons and spin-polarized fermions, it is well known that an attractive BF interaction leads to a so-called pairing phase in the strongly correlated regime [1]. This phase collapses if the interaction becomes too strong, resulting in clumping of the atoms and breaking of translational invariance. At the same time, deep optical lattices on BF mixtures render their description amenable to the BF Hubbard model, since an insulating phase of composite fermions is formed [2].

In our work, the bosons reside in the deep superfluid regime and inherit the periodicity of the optical lattice, subsequently serving as a dynamic potential for the polarized fermions. Owing to the atom-phonon interaction between the fermions and the condensate, the coupled system exhibits a Berezinskii-Kosterlitz-Thouless transition from a Luttinger liquid to a Peierls phase. However, under sufficiently strong BF interaction, the Peierls phase loses stability, leading to either a collapsed or a separated phase. We find that the primary function of the optical lattice is to stabilize the Peierls phase. Furthermore, the presence of a confining harmonic trap induces a diverse physical behavior, surpassing what is observed for either bosons or fermions individually trapped. Notably, under attractive BF interaction, the insulating phase may adopt a fermionic wedding-cake-like configuration, reflecting the dynamic nature of the underlying lattice potential. Conversely, for repulsive interaction, the trap destabilizes the Peierls phase, causing the two species to separate [3].

We acknowledge financial support from VR-Vetenskapsrådet (The Swedish Research Council), and KAW (The Knut and Alice Wallenberg foundation).

[1] M. A. Cazalilla and A. F. Ho, Phys. Rev. Lett. 91, 150403 (2003); T. Miyakawa, H. Yabu, and T. Suzuki, Peierls instability, Phys. Rev. A 70, 013612 (2004); M. Rizzi and A. Imambekov, Phys. Rev. A 77, 023621 (2008).

[2] M. Lewenstein, L. Santos, M. A. Baranov, and H. Fehrmann, Phys. Rev. Lett. 92, 050401 (2004); L. Pollet, M. Troyer, K. van Houcke, and S. M. A. Rombouts, Phys. Rev. Lett. 96, 190402 (2006).

[3] A. Gagge, Th. K. Mavrogordatos, and J. Larson, Phys. Rev. Research 6, 013138 (2024).