Elementary excitation of spin-orbit coupled Bose-Einstein condensates in optical lattice

Xu-Dan Chai and Ju-Kui Xue*

Key Laboratory of Atomic & Molecular Physics and Functional Materials of Gansu Province, College of Physics and Electronics Engineering, Northwest Normal University, Lanzhou 730070, China

Synopsis The phonon mode excitations of spin-orbit (SO) coupled Bose-Einstein condensates (BECs) trapped in an one-dimensional optical lattice are studied and the sound speed of the system is obtained analytically.

The elementary excitation and collective mode, which are the low-energy excitation of the system and can be precisely measured, play important roles for simulating more complicated and correlated condensed matter systems with Spin-orbit (SO) coupling [1]. Motivated by the rapid experimental and theoretical progress in these areas, great deal of works have been done to explore the properties of the SO coupled BECs. Especially, the SO coupled BECs in optical lattice has become a subject of immense interest theoretically and experimentally [2]. However, the analytical description of the low-energy excitation of the SO coupled BECs in optical lattice is still missing.

Under the mean field theory, by using the perturbation method [3], the sound speed of SO coupled BECs trapped in an one-dimensional optical lattice for zero momentum and plane wave phases regimes are derived analytically, respectively. The most obvious phenomenon is the softening of the phonon,i.e., the vanishing of sound speed in optical lattice. Without lattice potential, the softening of phonon mode occurs only at the phase transition point exactly, which is not affected by the atomic interaction strength and Raman coupling when the SO coupling is strong. However, considering the optical lattice, the softening of phonon modes takes place in a regime near the phase transition point. Interestingly, the regime is widened as lattice strength and SO coupling increase or atomic interaction decreases. The suppression of the sound speed by lattice strength relies on atomic interaction, Raman coupling, and SO coupling. Furthermore, we find that the sound speed in plane wave phase regime and zero momentum phase regime behaves very different characters for Raman coupling and SO coupling changing. In zero momentum phase regime, sound speed monotonically increases/decreases with Raman coupling/SO coupling. However, in plane wave regime, sound speed can either increase or decrease with Raman coupling and SO coupling, which strongly depends on the atomic interaction. Physically, phonon mode softening indicates the the appearance of the dynamical instability and the disappearance of the superfluidity. Specially, the presence of the optical lattice enhances this instability.

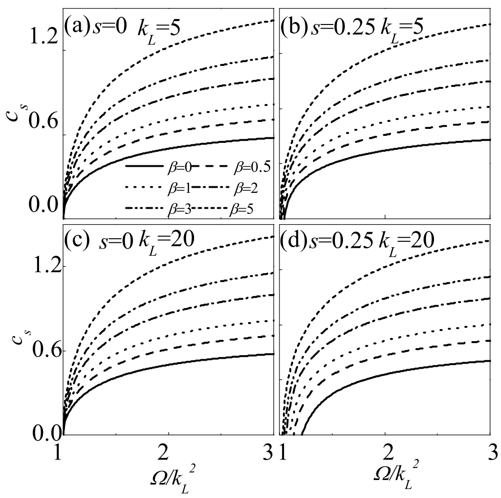

Figure 1. Sound speed against Raman coupling for different atomic interaction in zero momentum phase regime

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References

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*E-mail: xuejk@nwnu.edu.cn