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The Evolution from BCS to BEC Superfluidity in Multiband Systems: Applications to Two-band Superconductors and Ultra-cold Fermi Gases

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In the first part of the talk, I review some early work about the evolution from Bardeen-Cooper-Schrieffer (BCS) to Bose-Einstein Condensate (BEC) superfluids in the context of multiband systems. I focus primarily on three-dimensional s-wave two-band superfluids with a possible Josephson coupling between bands and discuss how collective modes evolve during the crossover from BCS to BEC superfluidity [1]. I also review the case where the Josephson interaction is tuned from negative to positive values leading to a quantum phase transition. In addition, I show that population imbalances between the two bands can be created by tuning intraband or interband interactions. Furthermore, I discuss the critical temperature of two-band superfluids, obtain the resulting coupled Ginzburg-Landau equations and show that they reduce to coupled Gross-Pitaevskii equations for two types of bosons in the BEC limit [2, 3]. In the second part of the talk, I present unpublished results on the evolution from BCS to Bose superfluidity for two-band fermions in two dimensions, including the cases of two particle (two hole) bands or of one particle and one hole bands. In these cases, I discuss also the critical temperature, the superfluid density tensor of the system and the resulting vortex-antivortex structures in connection to the Berezinskii-Kosterlitz-Thouless (BKT) transition [4]. For the two-dimensional case, possible connections are made to experimental systems consisting of two-band ultra-cold fermions such as ^{6}Li or ^{40}K, as well as, of two-band superconductors such as FeSe.

[1] M. Iskin and C. A. R. Sá de Melo, "BCS-BEC crossover of collective excitations in two-band superfluids", Phys. Rev. B **72**, 024512 (2005).

[2] M. Iskin and C. A. R. Sá de Melo, "Two-band superfluidity from the BCS to BEC limit", Phys. Rev. **74**, 144517 (2006).

[3] M. Iskin and C. A. R. Sá de Melo, "Evolution of two-band superfluidity from weak to strong coupling", J. Low Temp. Phys. **149**, 29 (2007).

[4] A. J. Buser and C. A. R. Sá de Melo, "Two-band superfluids in two-dimensions: evolution from weak to strong coupling", unpublished (2018).