The Evolution from BCS to BEC Superfluidity:

A Functional Integral Approach

Carlos A. R. Sá de Melo
Georgia Institute of Technology, Atlanta, USA

In these three lectures, I will review the evolution from BCS to BEC superfluidity for spin-1/2 fermions in three dimensions using the functional integral approach. In the first lecture, I will discuss the BCS-BEC evolution for s-wave interactions and show that there is just a crossover between the two limits, where an indirect gapped superfluid in the BCS side evolves smoothly into a direct gapped superfluid in the BEC regime [1, 2]. In the second lecture, I will analyze the same problem for p-wave interactions and demonstrate that a topological quantum phase transition takes place between the gapless BCS phase and the fully gapped BEC limit [3, 4]. Finally, in the third lecture, I will add spin-orbit and Zeeman fields to the s-wave problem and show that it induces a p-wave triplet component in the order parameter, thus producing a rich phase diagram containing gapless and fully gapped phases as interactions, spin-orbit and Zeeman fields are tuned [5, 6, 7].

[1] C. A. R. Sá de Melo, J. R. Engelbrecht and M. Randeria, Crossover from BCS to Bose superconductivity: Transition temperature and time-dependent Ginzburg-Landau theory, Phys. Rev. Lett. **71**, 3202 (1993).

[2] J. R. Engelbrecht, M. Randeria and C. A. R. Sá de Melo, BCS to Bose crossover: broken symmetry state", Phys. Rev. B **55**, 15153 (1997).

[3] M. Iskin and C. A. R. Sá de Melo, Evolution from BCS to BEC superfluidity in p-wave Fermi gases", Phys. Rev. Lett. **96**, 040402 (2006).

[4] M. Iskin and C. A. R. Sá de Melo, Nonzero orbital angular momentum superfluidity in ultracold Fermi gases, Phys. Rev. A **74**, 013608 (2006).

[5] Kangjun Seo, Li Han, and C. A. R. Sá de Melo, Emergence of Majorana and Dirac particles in ultracold fermions via tunable interactions, spin-orbit effects, and Zeeman fields, Phys. Rev. Lett. **109**, 105303 (2012).

[6] Kangjun Seo, Li Han, and C. A. R. Sá de Melo, Topological phase transitions in ultracold Fermi superfluids: The evolution from Bardeen-Cooper-Schrieffer to Bose-Einstein-condensate superfluids under artificial spin-orbit fields, Phys. Rev. A **85**, 033601 (2012).

[7] P. D. Powell, G. Baym, and C. A. R. Sá de Melo, Superfluid transition temperature of spin-orbit and Rabi coupled fermions with tunable interactions, arXiv:1709.07042v1 (2017).