Non-adiabatic superconductivity in two-dimensional hexagonal materials

D. Szczęśniak[1,*]

[1]Institute of Physics, Faculty of Science and Technology, Jan Długosz University in Częstochowa, 13/15 Armii Krajowej Ave., 42200 Częstochowa, Poland
*d.szczesniak@ujd.edu.pl

Two-dimensional (2D) hexagonal materials constitute a promising platform to explore phonon-mediated superconductivity under spatial confinement [1]. One of the most interesting aspects in this regard is the ability of these systems to host a superconducting phase that cannot be fully described within the standard Bardeen-Cooper-Schrieffer (BCS) theory. This stems not only from the presence of strong electron-phonon coupling and retardation effects in such materials [2–4], but also from their often comparable electronic and phononic energy scales [5]. Notably, the latter can lead to the breakdown of Migdal's theorem and the emergence of non-adiabatic phenomena, affecting the thermodynamic properties of the superconducting state [5].

The present contribution attempts to address the above effects and provide an overview of phonon-mediated superconductivity in 2D hexagonal systems. The discussion is primarily based on the Eliashberg formalism, which extends conventional BCS theory to include strong-coupling, retardation, and non-adiabatic corrections. It considers not only the mechanisms that lead to the induction of the superconducting state in 2D hexagonal materials [5, 6], but also possible routes to enhance this phase [7, 8]. In particular, the non-adiabatic effects are shown to play an important role in shaping the superconducting properties of representative 2D hexagonal systems. Their impact is illustrated through characteristic thermodynamic observables, including the critical temperature and superconducting gap. Moreover, the scalability of these effects is found to provide deeper insight into the underlying physics of discussed 2D superconductors and to suggest guidelines for future design of low-dimensional materials with improved superconducting properties [7,8]. The analysis is given with special attention to structural instabilities, external perturbations, and doping, allowing to identify limitations of the 2D platform. As a future perspective, the combined effect of dimensionality reduction and hydrogen doping on the superconducting phase is discussed using the example of 2D metal hydrides.

References

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