New phenomenology from an old theory – the BCS theory of superconductivity revisited

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We revisit the Bardeen-Cooper-Schriefer (BCS) theory of superconductivity by studying the effect of the asymmetry of the attraction band with respect to the chemical potential on the physical properties of the superconductor. The attraction band is defined as the interval $I_V = [\mu - \hbar\omega_c, \mu + \hbar\omega_c]$ in which the pairing interaction is manifested. In the "standard" BCS formalism, μ, which is the center of the attraction band, is identified with the chemical potential. Nevertheless, this is not a physical requirement and in multiband superconductors the cutoff of the pairing interaction may be asymmetric with respect to the chemical potential in some of the conduction bands. Furthermore, the chemical potential and the attraction band may be influenced differently by the external conditions (e.g. pressure) or preparation methods (e.g. changing the conduction band by changing the chemical composition of the superconductor), so it is natural to assume that μ is not identical to the chemical potential.

We consider here single-band superconductors and we denote the chemical potential by μ_R to distinguish it from μ. We analyze the effect of the difference $\mu - \mu_R$ on the physical properties of the superconductor. We find that if $\mu \neq \mu_R$, the energy gap Δ and the temperature of the superconductor-normal metal phase transition T_{ph} change and there are two solutions for the energy gap equation; the ratio $\Delta(T = 0)/T_{ph}$ changes also with $\mu - \mu_R$. More dramatically, when $\mu \neq \mu_R$, a population imbalance appears in equilibrium and the superconductor-normal metal phase transition becomes of the first order in the grandcanonical ensemble. If $\mu - \mu_R$ varies monotonically with pressure or doping, then a feature like the superconducting dome appears when the temperature of the phase transition is plotted vs pressure or doping concentration (for details, see Refs. [1,2]).

[1] D. V. Anghel and G. A. Nemnes, Physica A 464, 74 (2016).

[2] D. V. Anghel, arXiv:1609.07931.