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Multiple solutions for the equilibrium populations in BCS superconductors

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It was recently shown that the BCS formalism leads to several solutions for the energy gap and the equilibrium quasiparticle distribution (D. V. Anghel, Physica A 464, 74, 2016; ibid. Physica A 2019). While this became quite obvious when the attraction band (which is the single-particle energy interval in which the pairing interaction is manifested) is asymmetric with respect to the chemical potential of the system (that is, the center of the attraction band μ is different from the chemical potential μ_R), I will show here that there are two solutions, with different energy gaps and quasiparticle populations even when $\mu = \mu_R$. One of the solution leads to the well-known BCS results, with an energy gap denoted here by $\Delta_1(\mu_R - \mu = 0, T)$ (where T is the temperature), whereas the second one leads to an energy gap $\Delta_2(\mu_R - \mu = 0, T) \leq \Delta_1(\mu_R - \mu = 0, T)$, for any T below the critical temperature – the critical temperature is the same for both solutions. In the second solution, the quasiparticle population is different from zero even at $T = 0$ and it was shown before (D. V. Anghel, Phyica A, 2019) that $\Delta_2(\mu_R - \mu = 0, T = 0) = \Delta_1(\mu_R - \mu = 0, T = 0)/3$.

Primary author: ANGHEL, Dragos-Victor (IFIN-HH)

Presenter: ANGHEL, Dragos-Victor (IFIN-HH)

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