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The reduced Hartree-Fock model for extended defects in a Fermi sea

Studying the defects in materials remains an important subject in condensed matter physics. Localized defects have been well understood in insulators [Cancès et al, 2008][Lahbabi, 2014]. In this article, we establish a new mean-field model to study the extended defects in metals (modeled by the Fermi sea), where electron-electron interactions are separately modeled by Yukawa and Coulomb interactions. These extended defects typically correspond to taking out a slab of finite width in a three-dimensional perfect material. We work under the framework of reduced Hartree-Fock description [Solovej, 1991], i.e., the Hartree-Fock model without the exchange term. Inspired by the techniques developed in [Frank et al., 2013] in order to study perturbations in a Fermi sea, and in [Hainzl et al., 2005 a, b, 2007, 2009] for the purpose of studying the mean-field perturbations of Dirac sea in quantum electrodynamics, we justify the model by showing the existence of minimizers, and the convergence of Yukawa minimizers (resp. energy) to Coulomb minimizers (resp. energy) when Yukawa parameter tends to zero. Furthermore, we give the characterization of Yukawa minimizers. Finally, we give numerical illustrations of Friedel oscillations [Friedel, 1952], which are oscillations due to the screening of impurities for quantum many-body fermionic systems. We show that the model-generated Friedel oscillation coincides with the theoretic prediction of Friedel oscillation formula.