On the initial stage of quasiparticle decay: A many-body perturbation theory perspective

Yaroslav Pavlyukh

Martin-Luther-University, Halle-Wittenberg, Heinrich-Damerow-Str.4, Halle, Germany

Generally, the addition or removal of a single particle in a many-body system does not correspond to an exact eigenstate of the system. Thus the resulting coherent excitation evolves in time. As discussed here, the evolution at short times upon the excitation with the energy ε exhibits a quadratic decay [with the rate constant $\sigma^2(\varepsilon)$]. Later on, after some time $\tau(\varepsilon)$, the exponential decay sets in. It is governed by another rate constant $\gamma(\varepsilon)$. This behavior is generic for many realistic finite and extended systems [1]. For a finite system it is possible to assess this behavior full numerically using an exact solution of the many-body problem. We present a simple model for the electron spectral function that links together all three aforementioned parameters and give a prescription for how the energy uncertainty $\sigma^2(\varepsilon)$ can be computed within the many-body perturbation theory. Our numerical results demonstrate that the model approach accurately reproduces the exact spectral function in a large range of energies even in the case of fragmented many-body states. We show that the central quantity of this study $\sigma^2(\varepsilon)$ can easily be computed exactly or from approximate theories [2] and, hence, can be used for their validation. We also point out how the set in time can be tested by means of attosecond spectroscopy.

As another application of our theory we inspect the initial and the long-time evolution of excitations in Fermi liquids by analyzing the time structure of the electron spectral function. Focusing on the short-time limit we study the electron-boson model for the homogeneous electron gas and apply the first-order (in boson propagator) cumulant expansion of the electron Green's function. In addition to a quadratic decay in time upon triggering the excitation, we identify nonanalytic terms in the time expansion similar to those found in the Fermi edge singularity phenomenon. We also demonstrate that the exponential decay in time in the long-time limit is inconsistent with the GW approximation for the self-energy. The background for this is the Paley-Wiener theorem of complex analysis. To reconcile with the Fermi liquid behavior an inclusion of higher order diagrams (in the screened Coulomb interaction) is required [3].

[1] Y. Pavlyukh, J. Berakdar, and A. Rubio, Phys. Rev. B 87, 125101 (2013)

[2] Y. Pavlyukh, J. Berakdar, J. Chem. Phys. 135, 201103 (2011)

[3] Y. Pavlyukh, A. Rubio, and J. Berakdar, Phys. Rev. B 87, 205124 (2013)