Available online at www.sciencedirect.com
SCIENCE DIRECT®

Annals of Physics 318 (2005) 245–265

ANNALS of PHYSICS

www.elsevier.com/locate/aop

Dynamical response functions in correlated fermionic systems

P. Bożek [a,*], J. Margueron [b], H. Müther [b]

[a] *Institute of Nuclear Physics, PL-31-342 Cracow, Poland*
[b] *Institut für Theoretische Physik, Universität Tübingen, Germany*

Received 12 November 2004; accepted 4 January 2005
Available online 14 March 2005

Abstract

Response functions in nuclear matter at finite temperature are considered beyond the usual Hartree–Fock plus random phase approximation (RPA) scheme. The contributions due to the propagator for the dressed nucleons and the corresponding vertex corrections are treated in a consistent way. For that purpose a semi-realistic Hamiltonian is developed with parameters adjusted to reproduce the nucleon self-energy as derived from realistic nucleon–nucleon interactions. For a scalar residual interaction the resulting response functions are very close to the RPA response functions. However, the collective modes, if present, get an additional width due to the coupling to multi-pair configurations. For isospin-dependent residual interactions we find strong modifications of isospin response functions due to multi-pair contributions in the response function. Such a modification can lead to the disappearance of collective spin or isospin modes in a correlated system and shall have an effect on the absorption rate of neutrinos in nuclear matter.

PACS: 21.65.+f; 24.10.Cn; 26.60.+c

Keywords: Response functions; Correlated fermions; Neutron matter; Many-body theories

* Corresponding author. Fax: +48126628458.
E-mail address: piotr.bozek@ifj.edu.pl (P. Bożek).

0003-4916/$ - see front matter
doi:10.1016/j.aop.2005.01.001

1. Introduction

The shell-model or independent particle model (IPM) has been very successful in describing basic features of nuclear systems. This means that nuclei are considered as a system of nucleons moving independently in a mean-field and the residual interaction between these particle or quasi-particles is supposed to be weak. Therefore, the response of the the system to an external perturbation can be calculated within the Fermi Liquid theory [1] in terms of linear response functions. These response functions are calculated assuming a Hartree–Fock (HF) propagator for the particle–hole excitations of the nucleons and including the residual interaction by means of the random phase approximation (RPA) approximation. In the long-wavelength limit or external perturbations with low momentum transfer, the residual interaction between the quasi-particles is usually parameterized in terms of Landau parameters.

This HF plus RPA scheme is typically used to determine, e.g., the neutrino propagator in hot and dense nuclear matter [2–7] and it has been found that the neutrino opacity is very sensitive to the details of these response functions. This quantity is very crucial for the simulation of astrophysical objects like the explosion of supernovae or the cooling mechanism for neutron stars [8,9].

The study of the response is also very important to determine the propagator of mesons or a photon in the nuclear medium. Therefore, such investigations have to be performed to explore, e.g., the possibility for a pion condensation [10,11] or the production and emission of mesons and photons from the hot dense matter obtained in heavy ion reactions [12–17]. Last but not least, the response function is also reflecting the excitation modes of nuclei.

However, the simple HF plus RPA scheme outlined above is applicable to nuclear systems only if effective nucleon–nucleon (NN) interactions like Skyrme [18] or Gogny [19] forces are employed. The IPM fails completely if realistic NN interactions are considered, which have been adjusted to describe the NN scattering data. Trying to evaluate the energy of nuclear matter from such realistic interaction within the HF approximation yields positive energies, i.e., unbound nuclei [20]. The reason of this deficiency of the HF approximation in nuclear physics are the correlations beyond the IPM approach, which are induced from the strong short-range and tensor components of a realistic NN interaction.

These correlations have a significant effect on the single-particle propagator for a nucleon in the nuclear medium. The spectral function still exhibits a quasi-particle peak. A sizable fraction, however, of the strength occurs at energies above and below the quasi-particle peak. For hole-states one typically observes that around 15% of the spectral strength is shifted to energies above the Fermi energy [21–23] which means that the occupation probability of those states is reduced from 100% in the case of the IPM approach to around 85%. Another fraction of the hole-strength is shifted to energies below the quasi-particle energies, which means that it should be found in nucleon knock-out experiments at large missing energies. These effects of correlations on the spectral distribution are confirmed in $(e, e'p)$ experiments (see e.g., [24]).