Project Title: Properties of finite systems including nuclei at high temperature and angular momentum

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1) Study of the effects of quantal and thermal fluctuations beyond the mean field on the nuclear chemical potential

We studied the effects due to quantal and thermal fluctuations beyond the BCS quasiparticle mean field on the chemical potential within a model, which consists of N particles distributed amongst Ω doubly folded equidistant levels interacting via a pairing force with parameter G. The results obtained at zero and finite temperatures T within several approaches such as the BCS, Lipkin-Nogami (LN) particle-number projection, self-consistent quasiparticle random-phase approximation plus LN (LN1+SCQRPA), and modified BCS (MBCS) theories are compared with the exact results, whenever the latter are available. The analysis of the numerical results show that, in general, the chemical potential of the equidistant multilevel pairing model depends on the parameter of the pairing interaction and temperature. It remains a constant in the middle of the spectrum only in the half-filled case within the mean-field approximation that neglects the self-energy corrections to the single-particle energies. Beyond the quasiparticle mean field, quantal and thermal fluctuations significantly alter the chemical potential as a function of G and/or T. As the result, the quantity that corresponds to the chemical potential but includes the effects due to particle (quasiparticle) number fluctuations, such as the parameter λ_{LN} within the LN method or λ within the MBCS theory, gradually loses its strict physical meaning as a chemical potential with increasing T, and as the approximate particle-number projection approaches the exact one, where all particle-number fluctuations are eliminated.

In the study of the chemical potential as a measure to search for the onset of BCS-Bose-Einstein condensation (BEC) transition in finite systems, we have shown that the system in the strong coupling regime can approach the BEC limit only in the strongly underfilled case (when the number N of particles is much smaller than the size, i.e. number Ω of the levels of the system) at zero temperature. Even if it can take place, increasing temperature will drive the system out of the BEC limit. However, this is a conclusion obtained here within a simple one-dimensional model. How this feature is modified in realistic nuclei remains a question to be answered in the future studies.

2) Proposing a novel approach, which embeds in the canonical ensemble the solutions of the selfconsistent QRPA

We propose an approach based on the solutions of the SCQRPA at zero temperature embedded into the canonical ensemble (CE). The proposed approach is tested within the Richardson model whose exact solutions are available as well as the realistic single-particle spectra of neutrons in ^{56}Fe nucleus. The analysis for the thermodynamic quantities such as the pairing gap, total energy and heat capacity shows that the CE-LNSCQRPA offers the best fits to the exact results of the Richardson model as well as the finite-temperature quantum Monte-Carlo calculations. As the result, the superfluid-normal phase transition predicted by the conventional BCS theory based on the grand canonical ensemble (GCE) is smoothed out even within the CE-BCS calculations due to the effects of quantal and thermal fluctuations. This feature suggests that any particle-number projection method at finite temperature, which could bring a GCE-BCS to CE-BCS, should have the same feature as presented here. Since the present approach does not involves any diagonalization route, its merit resides in its simplicity and its applications to larger finite systems where the exact calculations are practically impossible or the quantum Monte-Carlo method is time consuming.

Fiscal Year 2009 List of Publications Resulting from the Use of RICC

[Publication]

1) **N. Dinh Dang and N. Quang Hung,** Chemical potential beyond the quasiparticle mean field, □*in production in Phys. Rev. C (to be published on March 3, 2010).* (PDF file of the manuscript is attached).

2) **N. Quang Hung and N. Dinh Dang**, Exact and approximate ensemble treatments of thermal pairing in a multilevel model, Phys. Rev. C 79 (2009) 054328.

[Oral presentation at an international symposium]

1) **N. Dinh Dang**
The Selfconsistent Quasiparticle RPA and Its Description of Thermal Pairing Properties in Nuclei, invited talk at the Multidisciplinary Workshop on RPA and extensions, January 26 - 28, 2010, Universite Pierre et marie Curie, Jussieu, Paris, **France**

2) **N. Dinh Dang**, N. Quang Hung, and P. Schuck
Quantal and thermal fluctuations in the BCS-BEC cross-over region within the pairing model (BCS-BEC transitions in finite systems), talk at the 3rd Joint meeting between the Nuclear Physics Divisions of the APS and JPS, October 13 - 17, 2009, Waikoloa Village, **Hawaii's Big Island**

[Other]:

Mr Nguyen Quang Hung, RIKEN Asian Program Associate, who has been working under my supervision at RIKEN since July 2006, has successfully got his PhD at the National PhD Committee on 5 November 2009 at the Institute of Physics (Hanoi -Vietnam), and has been selected as the Nishina Memorial Fellow working at RIKEN under my supervision starting from Dec. 6, 2009 for 6 months.