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Non-linear Canonical Methods in Strongly Correlated Electron Systems

Foundations and Examples

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Akademisk avhandling för filosofie doktorsexamen i Fysik, som med tillstånd från Naturvetenskapliga fakulteten kommer att offentligt försvaras tisdag den 16 december 2014 kl. 13.00 i sal PJ, Institutionen för fysik, Fysikgården 1, Göteborg.

ISBN: 978-91-628-9186-2

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In this thesis some new ideas to perform the analysis of Strongly Correlated Electronic Systems (SCES) are developed. In particular the use of non-linear canonical transformations is considered thoroughly. Using such transformations it is possible, in some circumstances, to simplify the quantum problem redefining the fermionic degrees of freedom used to describe the system. To understand and use effectively these non-linear transformations it is convenient to work in the Majorana fermion representation, i.e., to represent the quantum mechanical operators in terms of Majorana fermions. These objects can be imagined as algebraic constituents of the fermionic degrees of freedom. In a fermionic system, different equivalent sets of (emergent) Majorana fermions can be used to build the fermionic operators that characterize the system. The non-linear transformations can be seen as a way to mix these equivalent sets. Thanks to this insight, it becomes possible to determine the full structure of the group of canonical transformations and to identify an advantageous framework, which allows their use in the study of a generic SCES system. To test these statements the Hubbard and the Kondo lattice models were intensively studied making use of non-linear canonical transformations, obtaining interesting results in both cases. For example, in the Hubbard model a free fermion mean-field description of the paramagnetic Mott insulator was identified, while in the Kondo lattice it was possible to describe already at mean-field level the spin-selective Kondo insulating phase, consistently (from a quantitative and qualitative point of view) with the known numerical results. Moreover the method elaborated for the study of the Hubbard model is suitable for a systematic generalization to other situations and shows great room for improvement. These results prove that, thanks to the redefinition of the degrees of freedom used in the analysis of the system, it becomes possible to obtain quite non-trivial results already at mean-field level, or to consider very involved (but meaningful) correlated quantum states via simple variational trial states. This will potentially permit a more judicious and profitable choice of the fundamental degrees of freedom, allowing for an improvement of the efficiency of the analytical and numerical techniques used in the analysis of many SCES systems.

The thesis is available on-line via: http://gup.ub.gu.se