Quantum Computing

Studies of Confined electron systems

Master of Science thesis project

December 1, 2022

Introduction and overview

The aim of this project is the study of time evolution in fermionic systems through the use of quantum many-body theory applied to candidate systems for realizing quantum circuits and gates. In particular we will analyze and study properties like the time evolution of entanglement and how to realize quantum gates for systems of electrons confined in one and two dimensions, so-called quantum dot systems [1].

Quantum many-body theory has provided methods to solve problems in such diverse areas as atomic, molecular, solid-state and nuclear physics, chemistry and materials science. In the past decades, static properties such as binding energies and various expectation values have been calculated. The introduction of time in these calculations yields an insight into the dynamics of quantum mechanical systems, such as the electron behavior under an external potential in quantum dots [1]. Specifically, the goal here is to develop a computational framework (codes and theory) for studies of interacting systems of electrons with time-dependence using time-dependent full configuration interaction theory [2, 3].

Based on the theoretical solutions and design of specific quantum gates, the final aim is to study the simulation of systems of specific quantum circuits as function of time. The aim is to simulate systems of two to at most ten electrons confined in various harmonic oscillator traps.

Strongly confined electrons offer a wide variety of complex and subtle phenomena which pose severe challenges to existing many-body methods. Quantum dots in particular, that is, electrons confined in semiconducting heterostructures, exhibit, due to their small size, discrete quantum levels.

Recently, several experimental groups have started to study how one can use confined eletrons to make quantum gates and circuits in order to implement different quantum computing algorithms. To study their feasibility using quantum mechanical simulation tools like time-dependent many-body methods can hopefully shed light on such candidate systems.

Specific tasks and milestones

The specific task here

1. Spring 2023: Start writing a time-dependent Hartree-Fock code applied to a system of two electrons in one dimension in one and thereafter two harmonic oscillator traps. Here we have in mind electrons confined in harmonic oscillator traps as done by the authors of Ref. [4]. Finalize remaining courses.

2. Fall 2023: Extend the program from spring 2023 to study time-dependent full configuration interaction [2, 3] and study systems of two and up to four interacting electrons in one or more harmonic oscillator traps. Study the time-evolution of entanglement for these systems.

3. Spring 2024: Extend the program to include the simulation of specific quantum circuits and the stability of such systems. Here one can think of devising various quantum gates like CNOT, iSWAP gates and other and study the feasibility of such quantum circuits.

The thesis is expected to be handed in May/June 2024

References

[1] Stephanie M. Reimann and Matti Manninen, Reviews of Modern Physics **74**, 1283 (2002), `https://doi.org/10.1103/RevModPhys.74.1283`

[2] Sigve Skattum, Master of Science Thesis, University of Oslo (2013), `https://www.duo.uio.no/handle/10852/37170`

[3] D. Hochstuhl, C.M. Hinz, and M. Bonitz, The European Physical Journal Special Topics **223**, 177 (2014), `https://link.springer.com/article/10.1140/epjst/e2014-02092-3`

[4] J. Zanghellini, M. Kitzler, T. Brabec, and A. Scrinzi, Journal of Physics B **37**, 763 (2004), `https://doi.org/10.1088/0953-4075/37/4/004`