Quantum Simulation with Trapped Ions in a Gradient Field

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Principal investigator

Roee Ozeri

Faculty of Physics
Department of Department of Physics of Complex Systems

Overview

Progress in a broad range of scientific and technological fields is hampered by the difficulty of understanding and predicting the behavior of highly complex systems. Simulating the behavior of these systems is difficult with classical computers but can be performed efficiently using quantum simulators. Currently, the scope of models which such simulators can accommodate with current techniques is restricted because of limitations in managing and configuring the ion chain. We have developed a novel technique for quantum simulation which significantly increase the range of models that can be implemented on a quantum simulator.

The Need

Quantum simulators are highly controlled quantum machines with which it is possible to engineer and study complex quantum states and dynamics. Such machines, when large and accurate enough, are expected to elucidate the behavior of quantum systems that defy analytical treatment and are intractable for classical numerical simulations1. Although quantum simulation is related to quantum computing, it is far easier and less costly to implement in many practical applications. Quantum simulation offers reduced system complexity, avoids the high engineering cost of universal gates and fault tolerant architecture to compensate for fidelity loss, uses much smaller qubit arrays, and does not require the development and debugging of complex algorithms in order to represent target models accurately and faithfully. The leading platform for quantum simulations is a chain of ions in a linear radio-frequency trap. However, a wide range of quantum models and phenomena have, so far, remained beyond the reach of such simulators because of limitations in managing and configuring the ion chain. For example, linear trapped ion simulators lack the ability to simulate magnetic flux, an important factor in many interactions and physical phenomena.

The Solution

Prof. Roee Ozeri and his team developed a novel method for quantum simulation with a chain of ions in a linear RF trap which expands the range of models that can be quantum-simulated.

Technology Essence

Current methods allow for interaction only between two adjacent ions limiting the flexibility and potential complexity of calculations. Prof. Roee Ozeri and his team invented a technique that will allow more complex interactions of also non-adjacent ions, enhancing the calculation possibilities of the system in a controlled manner by applying a magnetic field. The heart of this technique is the addition of an external field gradient in combination with specific laser spectral content, which together modify the ion array and/or the interaction of the laser with the ion array in a particular way that benefits quantum simulation. This technique can be used also to generate both static and timevarying synthetic gauge fields in a linear chain of trapped ions and enables continuous simulation of a variety of coupling geometries and topologies, including periodic boundary conditions and high-dimensional Hamiltonians.

Applications

- Atomic and molecular physics.
- Chemistry - molecular simulations and drug discovery.
- Material engineering.

Advantages

- Enables scientists and developers to understand the molecular formations that underly chemical and drug discovery.
- Expands the range of molecules available for simulation with trapped ion platforms.
- Solves optimization problems, which are prevalent in many technological applications.
- Simulates complex quantum phenomena in condensed matter, high energy, chemical, atomic and molecular physics.

Development Status

Currently, the idea is theoretical. Validations and proof of-principle experiments will be executed within the next few months.

Market Opportunity

Successful marketing of quantum computers and quantum simulators will likely have large benefits. Relevant markets and potential clients are the academia for developed technology, and companies that are developing quantum simulator in the ion trap technology (such as Honeywell ionQ and Infineon).

References

Feynman R. P., (1982). Simulating physics with computers. Int. J. Theor. Phys. 21, 467 DOI: 10.1007/BF02650179 [1]

Manovitz, T., Shapira, Y., Akerman, N., Stern, A., & Ozeri, R. (2020). Quantum simulations with complex geometries and synthetic gauge fields in a trapped ion chain. PRX Quantum, 1(2), 020303.? DOI: 10.1103/PRXQuantum.1.020303 [2]

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