Quantum Computing with Cold Atoms

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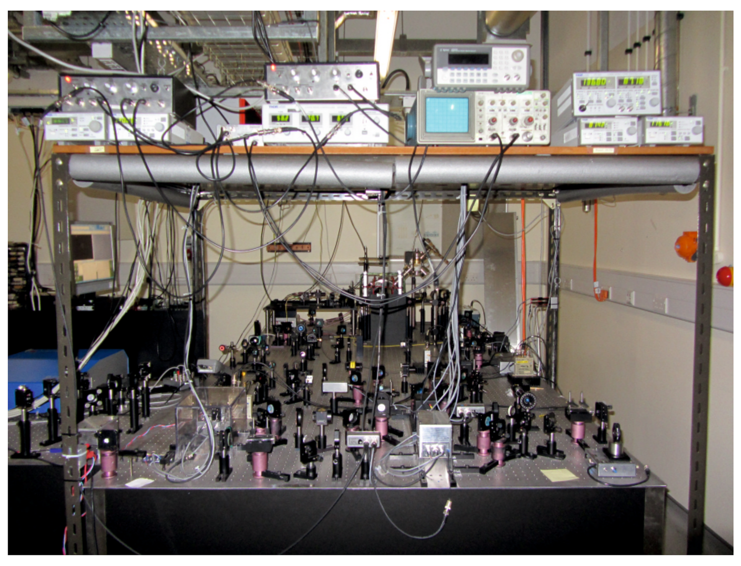
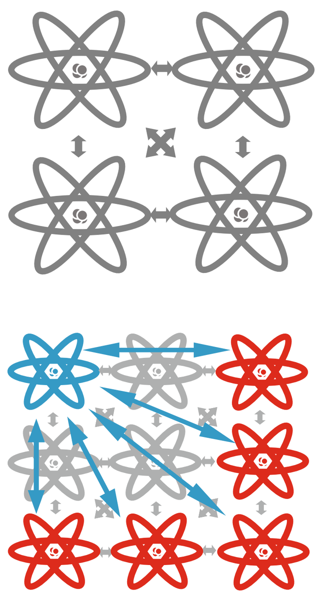
What is the aim of project?

Quantum and classical computing have a lot in common. The general concept of computing requires following constituents: the way to store information; the way of processing information; and the way to encode the final result of information processing. In Quantum Computing (QC) any physical two-state system in which quantum effects play the dominant role might become a unit of quantum memory called quantum bit (qubit). So far, the basic quantum memory unit, and a simple processing system have been successfully created. However, the scalability (a possibility of expanding) of these systems still remains an unsolved issue.

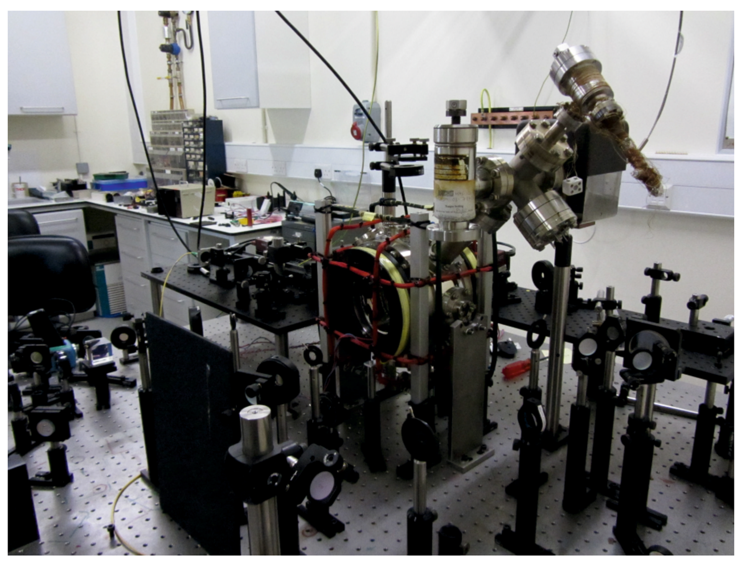


Main optical table with vacuum chamber



Our group proposed a completely new experimental approach to the topic of quantum computation, based on promising recently developed quantum protocol called 'Deterministic quantum computing with one clean qubit' (DQC1). The aim of the project is the proof of concept using cooled trapped atoms.

Scheme presents the concept of scalability. Latice of qubits is expanded hence the interactions between qubits become more complex.



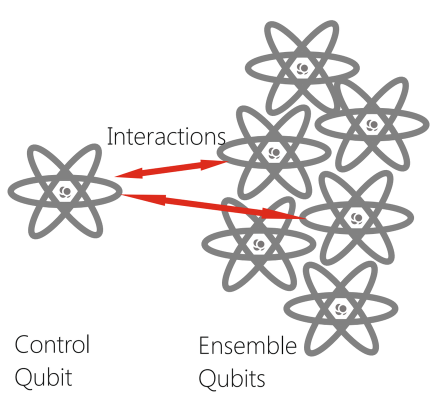
Vacuum chamber with Rubidium atoms

Experimental setup

Our project is the first attempt to use atoms to prove the scalability of the DQC1. Here, cold Rubidium atoms play the role of qubits.

Rubidium atoms are placed inside the vacuum chamber in a gas form. High vacuum prevents collisions between Rubidium and background gases, as well as between different themselfs. Then, atoms are trapped and loaded in a Magneto Optical Trap (MOT). This cools down atoms and concentrate them into a small dense cloud in the middle of the vacuum chamber.

Scheme presents the concept of DQC1. Single atom interacts with a cloud of atoms. It is important to ensure the same interaction strength between the control atom and each of ensemble atoms.



Some of atoms trapped in MOT are selected by additional highly focussed laser beam. This method is called dipole trapping or optical tweezer. It allows to create the two dimensional lattice of single traped atoms.

Atoms emits fluorescence light in all directions due to interaction with laser light. This signal might be captured and used for observing the result of experiment. Our imaging system is based on photodiode and a variety of CCD cameras.

A system of lasers to control selected atoms states is required. This consists of a very strong blue laser light and two very stable infrared lasers.

Conclusions

Quantum computing is a promising branch of science which is expected to solve a wide range of computational problems in a much more efficient way than the classical methods. Our group proposed a completely new experimental approach to the topic of quantum computation, based on promising recently developed quantum protocol called 'Deterministic quantum computing with one clean qubit' (DQC1). This protocol enables us to scale-up computational system in relatively easy way. Our experimental setup consists of all required components. Information is encoded in ground state of cold Rubidium atoms. Using an appropriate laser light we are able to precisely control the state of atoms, switch on and off so-called Rydberg interactions and hence perform quantum computation.

Want to know more?

Concepts of Quantum Mechanics

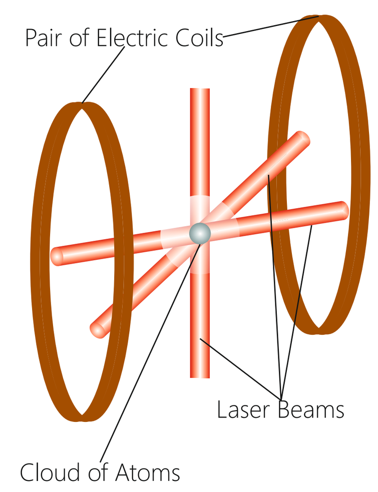
- Quantum state - a description of system in which **quantum effects** are dominant. Quantum systems evince features, like **superposition** or **entanglement.**
- Pure states - a quantum state that cannot be represented as a combination of other states.
- Mixed states - a quantum state that can be composed by mixture of other quantum states with some probability of occurrence.

DQC 1 protocol

Deterministic Quantum Computations with one Clean qubit (DQC1) is one of the recently developed quantum protocol. Here information is stored in one well controlled pure qubit and ensemble of qubits in 'mixed' states.

The key point of DQC 1 is that all qubits play role in processing information but only the state of the controll one is actually measured. Although DQC1 does not provide universal computation, it can provide speed up of specific classically intractable computational tasks. In this protocol, which can be easily extended by additional qubits in ensembles, scalability is much more easily obtained.

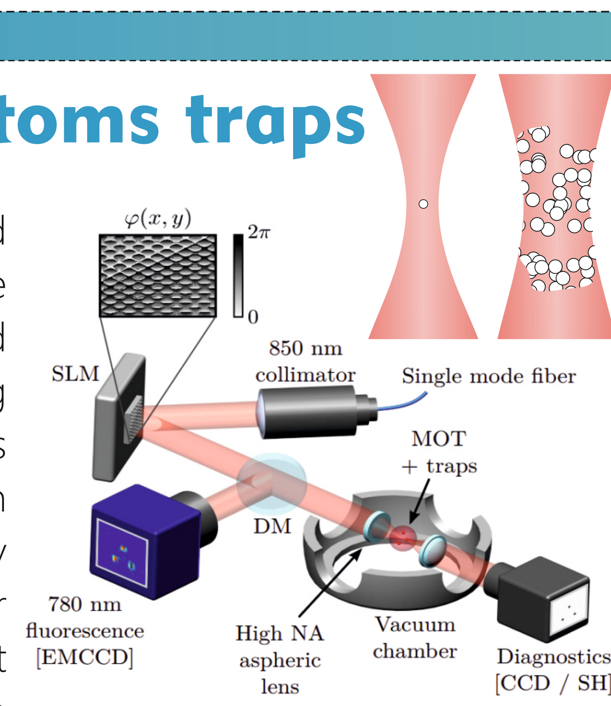
Magneto Optical Trap

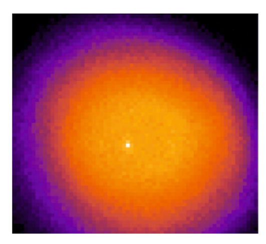


Six laser beams cross through the central point. Laser light is absorbed by atoms and then the absorbed energy is emitted in random directions. The average difference of momentum leads to slowing down and cooling of atoms. A pair of electric coils create a non uniform magnetic field that results in trapping atoms in the center.

2D Array of atoms traps

Atoms, previously cooled down by MOT, might be trapped in highly focussed near infrared laser. Obtaining two dimensional array requires many laser beams focussed in such a way. This might be easily o obtained from a single laser beam using Spatial Light Modulator (SLM). This device creates an arbitrary pattern of light from a single beam.

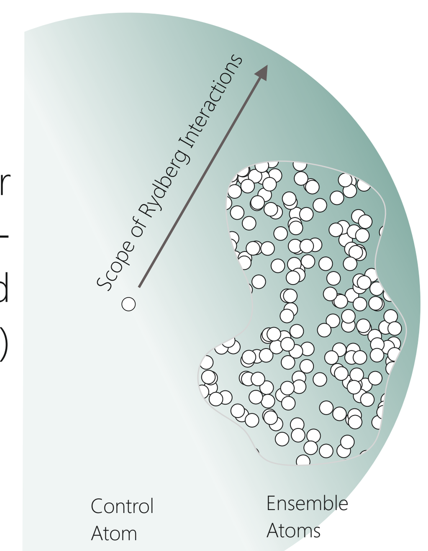


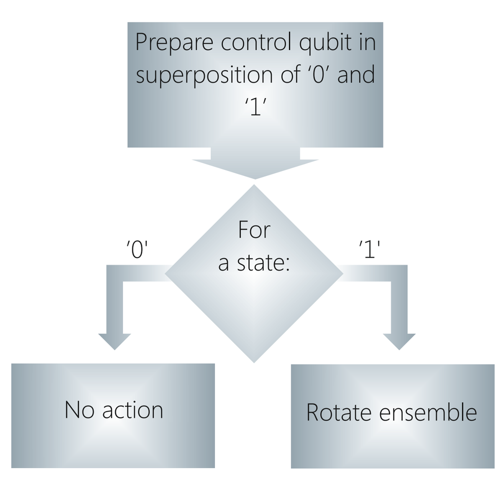


Fluorescence image of the atoms (orange area) and a single dipole trap in the middle (white pixel).

Atoms' State Control

The key phenomenon responsible for controlling interactions between atoms is so-called Rydberg blockade. Highly excited Rubidium atoms (to so called Rydberg states) interact with each other.





If the control qubit is in a state 1, then laser light provides a transition from ground state to Rydberg state. This activates Rydberg interactions between control atom and ensemble, so that the state of ensemble atoms may be changed now.