How a Quantum Computer could be built using Rare Earth Ions

Quantum Computers have the potential to transform how research is done in many different fields. Analogously to classical computers whose fundamental unit is a binary value, the ”bit”, quantum computers can run calculations using ”qubits”. Instead of taking either value 0 or 1, qubits can also be in between. Practically, this could mean that an atom exists in two different energy levels at the same time, a state which is predicted by quantum theory and can be achieved experimentally using laser light and really cold temperatures. This property makes certain calculations much more efficient than on any classical computer because many different calculations can be run simultaneously. A quantum computer's prediction could for example revolutionize how we use molecules in pharmaceutical research.

The approach to this subject in Lund is based on rare earth ions, yttrium (element 39) and everything from lanthanum (element 57) to lutetium (element 71). Doped into crystals, it is exactly the above mentioned superposition of energy states that is treated as the qubit. At close to the absolute zero temperature (achieved using liquid helium), this superposition can be held alive for a very long time. This property, referred to as long coherence time, makes the rare earths especially suitable for quantum computers because the computations cannot happen instantaneously. At the same time, short coherence times are needed when the result of the computation is to be read out. The dilemma is therefore that long coherence times are needed for the computation to run but short coherence times are necessary for reading out the result.

This enigma is on its way to being solved by incorporating a second type of rare earth ion into the crystals. By interacting with neighboring atoms, it communicates with the qubit ions but would itself not be involved in the calculations, only being used for reading out the final state. But because it also has a non negligible coherence time, another trick needs to be employed based on a quantum effect named after its discoverer ”Purcell”. This can be achieved by placing the crystals between two mirrors that form a cavity. At sufficiently small mirror distances the coherence time is reduced by the Purcell effect. Hence, using nano crystals it should be possible to decrease the coherence time of the read out ion.

One of the mirrors of the cavity can be made extremely small when an optical fiber is used as base material. On its tip a curvature can be molded and then a mirror coating can be applied onto it. This is exactly what has been done by a German research group and they have also tested the cavity effects at really cold temperatures. However, their cooling system differs from the one available at Lund University such that their approach could not easily be reproduced in our group. It was the task of this thesis to built a holder for the fiber to be placed in. In addition to fitting into our cooling system, the requirements for the holder were the ability for the fiber to move in all three directions but to be very stable once an appropriate position is found.

If successful, this method opens a new chapter for the quantum computing research in Lund and all over the world.

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