# Entangling the Lattice Clock with Rydberg Gates

**Frank Greenhalgh**
University of Nevada, Reno Physics Department

## Introduction

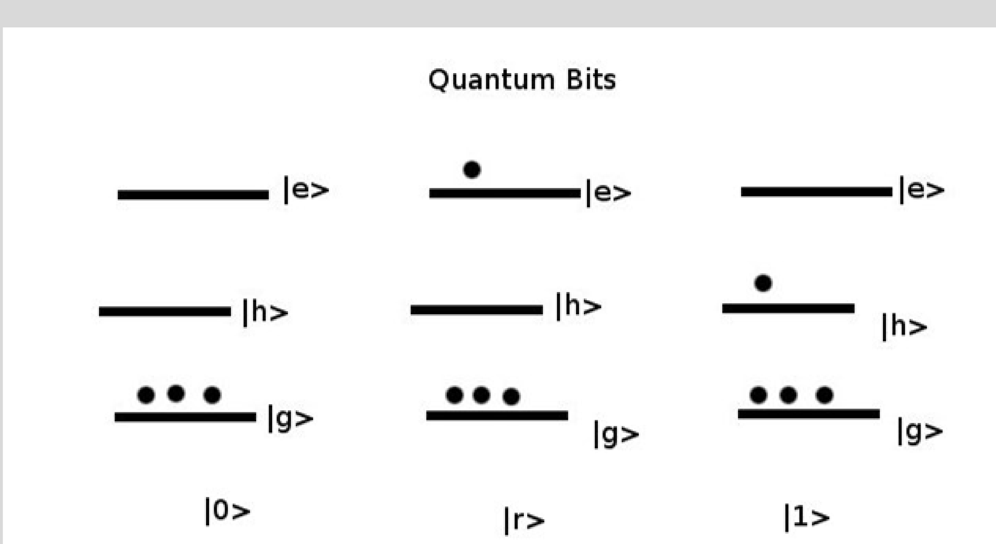
Modern atomic clocks measure time by counting oscillations of a local oscillator whose frequency is set by the transitions of atoms in a linear optical lattice. The local oscillator's (laser) frequency, ω, may be found by measuring the probability that the atoms make a transition when a laser is shined on them. When the probability of transition is a maximum, the resonant frequency has been found.

When N unentangled atoms are measured, the signal to noise ratio goes up as √N. When these atoms are entangled the signal to noise ratio goes up proportional to N [2].

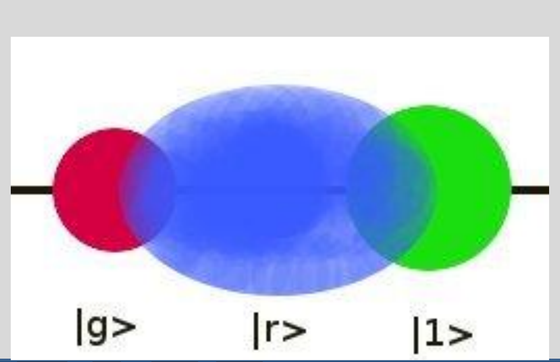
The modern atomic clock's shortcoming is that the electron movement is random in the atoms that are responsible for the time measurements. Entangling the atoms increases the sensitivity of the measurement.

## Problem

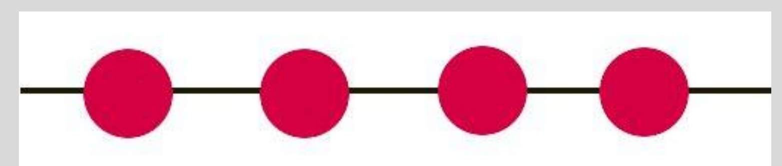
Using the following cluster states as qubits, the Greenberger–Horne–Zeilinger (GHZ) state will be created.



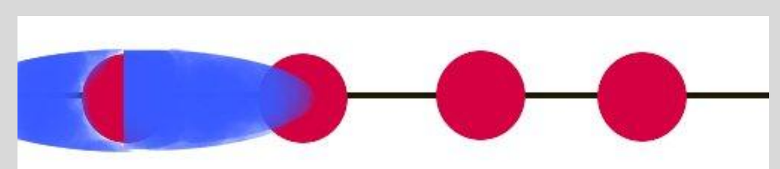

These cluster states will be represented in a lattice as shown below. The Rydberg state qubit is "shown blocking" the others from being promoted to the Rydberg state.



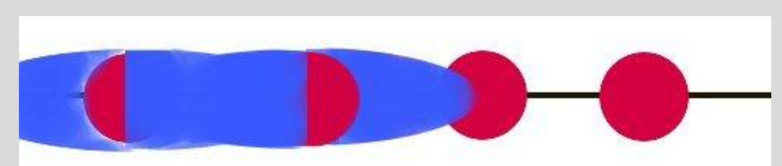

## Methodology



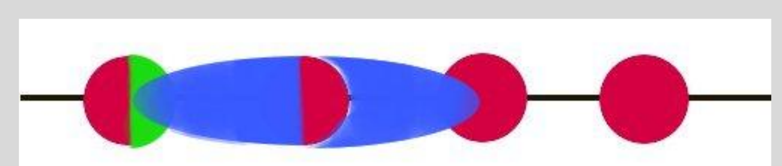
|Ψ>=|0000>



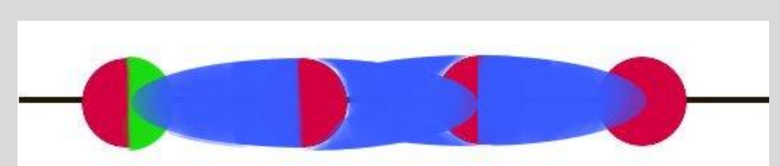
|Ψ>=(1/(√2))(|0>+|r>)|000>



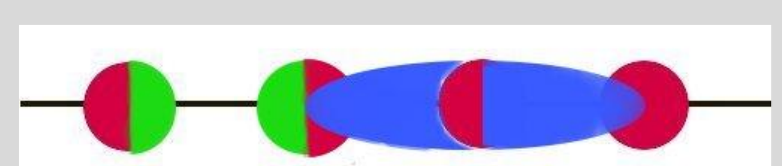
|Ψ>=(1/(√2))(|0r>+|r0>)|00>



|Ψ>=(1/(√2))(|0r>+|10>)|00>

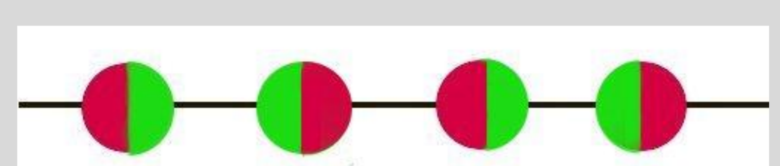


|Ψ>=(1/(√2))(|0r0>+|10r>)|0>

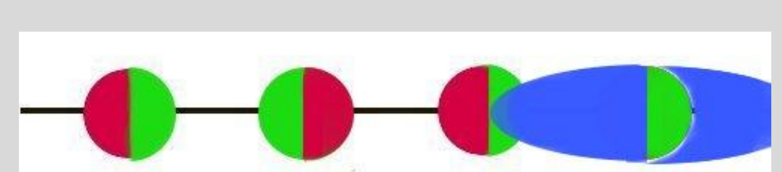


|Ψ>=(1/(√2))(|010>+|10r>)|0>

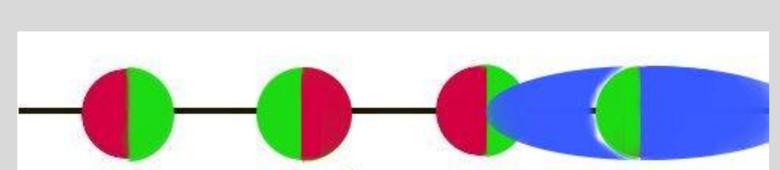
In this way, we get the state with all the qubits in a GHZ-like state.



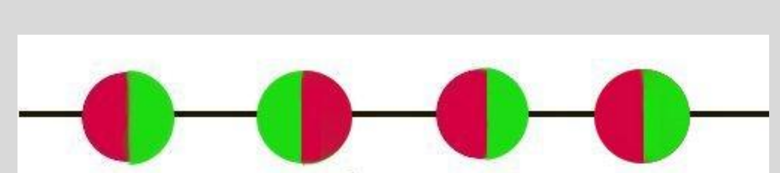
|Ψ>=(1/(√2))(|0101>+|1010>)



Every other qubit must be flipped to get an entangled state with different energies:
|Ψ>=(1/(√2))(|010r>+|1010>)

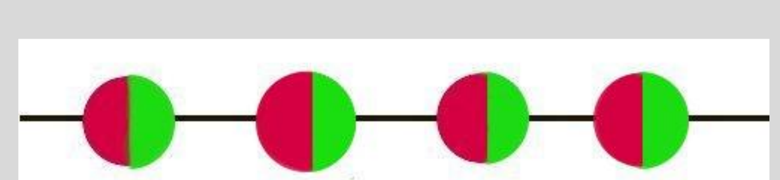


|Ψ>=(1/(√2))(|0100>+|101r>)



|Ψ>=(1/(√2))(|0100>+|1011>)

Flopping every other qubit we get,



|Ψ>=(1/(√2))(|0000>+|1111>)

## Conclusions

An entanglement scheme has been given. This entanglement scheme shall be used in an atomic clock as discussed below.

First, the GHZ will be produced by the process given. Then the state will be allowed to evolve on its own for a set amount of time. The |1111> part of the state evolves faster since it has more energy and thus a higher frequency. This will create an overall complex phase difference between the two states.

After the set evolution time, this phase difference can be mapped into measurement probabilities by applying the GHZ scheme in reverse order. This final state is measured.

## References

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