Physical implementations of quantum computers

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Quantum protocols with photons

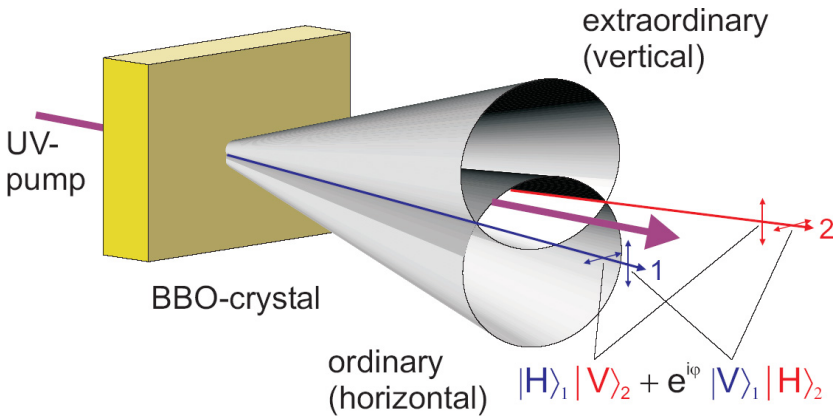
A lot of protocols require entanglement

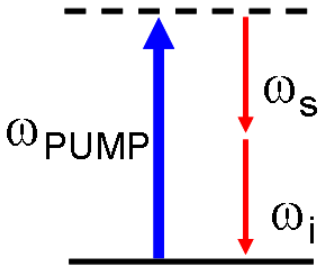
- Quantum teleportation
- Cheating at bit commitment
- Quantum cryptography (E91)
- Etc.

How to create a Bell state?

- Spontaneous parametric down-conversion
- Non-linear medium
- Probabilistic process
- Inefficient way of producing quantum resources

Quantum protocols with photons





Efficiency

- Suppose pulsed operation with 100 MHz repetition rate: 10^8 pairs per second?
- Output state $|\Psi\rangle = \sum_{n=0}^{\infty} C_n|n,n\rangle$ where $\{C_n\}$ depend on the power of the pump
- Low power to avoid double pairs: 1% efficiency
- Low detection efficiency: 10% success rate
- From 100 MHz to 100 kHz
- Want 2 pairs simultaneously? $\rightarrow$ 100 Hz!
- Want 3 pairs simultaneously? $\rightarrow$ 0.1 Hz!!!
- The solution: quantum memory

Quantum memory

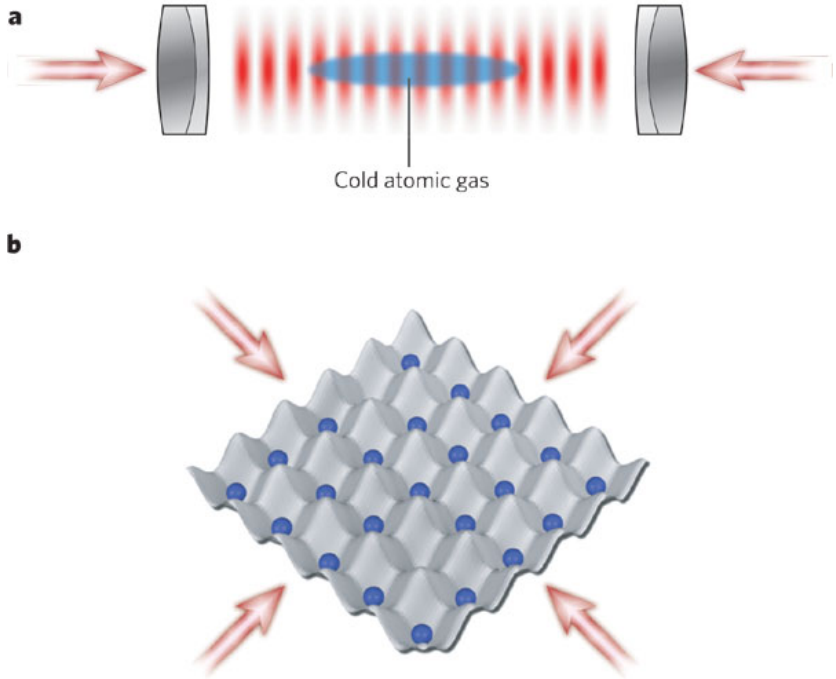
- The problem with photons: they never stop propagating and they are fragile
- Transfer the state of the photon to an ensemble of absorbers and retrieve it at a later time
- For instance, gas of atoms
- Atoms should not move: ultracold temperature, 1 μK above absolute zero!
- Crucial element for long distance quantum communications (e.g. BB84) $\rightarrow$ *quantum repeater*

Gates for universal quantum computing

- One can implement any algorithm with a reduce set of gates, e.g. {all single qubit rotations, CNOT}
- Need at least one 2-qubit gate
- Physically, corresponds to interaction between qubits
- Single photons do not interact $\rightarrow$ probabilistic gates
- Material systems can interact, e.g. atoms

Cold atoms in optical lattices

Ultracold atoms trapped in standing waves



Requirements?

- Many well-defined qubits: scalable
- Initialisation: ultracold temperature $\rightarrow$ Bose-Einstein condensates at a 100 nK above absolute zero!
- Quantum gates: work in progress
- Qubit-specific measurement: hard because the atoms are so close
- Long coherence times: hard even for neutral atoms

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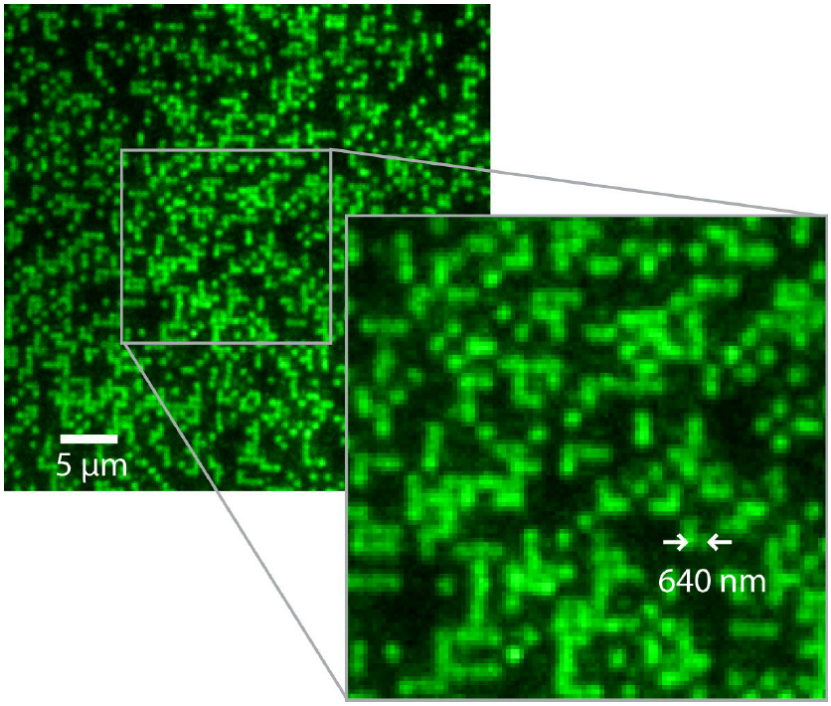
Imaging the atoms

Experimental progress with state-of-the-art imaging techniques



Rydberg gate

- Challenge: strong interaction between isolated qubits
- Idea: turn the interaction on only during gate operation
- Rydberg states are highly excited states with long-range electric interaction