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 $\mu$K 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
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