Quantum Computers

Ladd et al., Nature 464, 45 (2010)

Motivation

- QC solves some problems faster:
  - Shor-Algorithm (facotring of large numbers)
    300-digit number:
    $\longrightarrow$ classical: 150 000 years
    $\longrightarrow$ QC: < 1s
  - Grover-Algorithm (efficient search)
- Simulation of quantum systems

Content

1. Important conepts
2. Photons
3. Trapped atoms
4. Quantum dots and dopants
5. Superconductor
6. Outlook

Important concepts

- Classical bit: value 0 or 1
- Qubit: |0>, |1> or any superposition

- Entanglement of many qubits (e.g. 2 qubits):
  |00>, |01>, |10>, |11> $\longrightarrow$ superposition

- N entangled qubits have 2^N states (qubit register)
  $\longrightarrow$ 1 operation on a qubit register effects 2^N manipulations

Important concepts

- Quantum operations with logic gates
  - ⟶ electron spins: magnetic fields
  - ⟶ energy levels in atoms: laser pulse
- CNOT-gate: two-qubit-gate
  - ⟶ interaction between qubits

C	T		C	T
0	0	→	0	0
0	1	→	0	1
1	0	→	1	1
1	1	→	1	0

- universel logic gate: CNOT-gate and all single-qubit-gates

Important concepts

Problems: decoherence

- Destroys entanglement because of interactions
  $\longrightarrow$ isolation of qubits

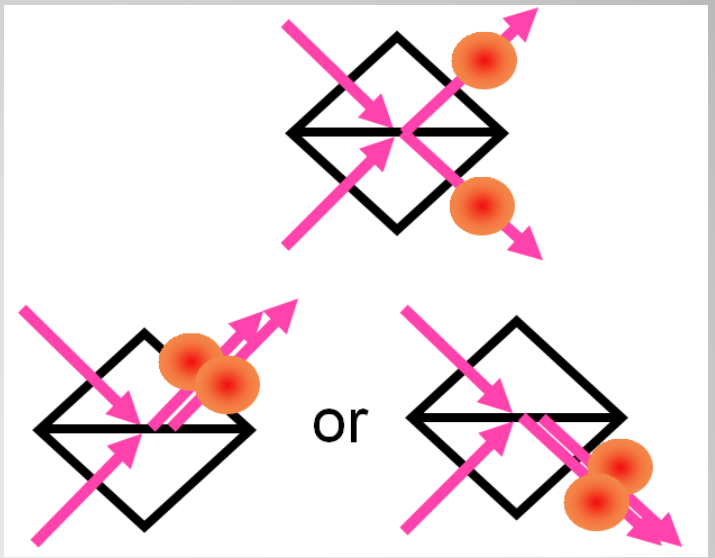
- long coherence time T_2
- Minimize decoherence effects through QEC

- Initialization of the system: extract entropy (for example laser cooling)

Technologies

Photons

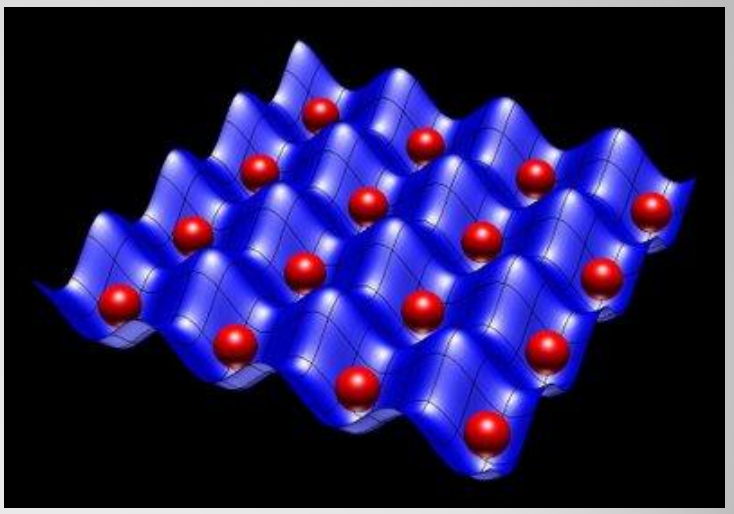
- Qubit: photon with horizontal or vertical polarization
- Manipulation: waveplates
- Entanglement:
  - Non linear optical crystalls
  - KLM-scheme: interference



- Problems: single-photon-source/detector and photon loss $\longrightarrow$ T_2 ~ 0,1 ms

Trapped atoms

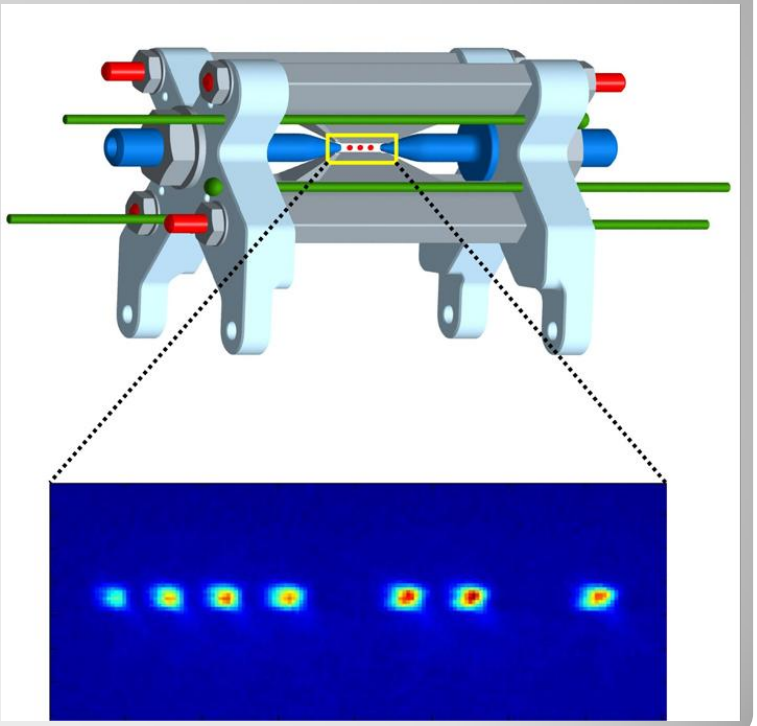
- Qubit: energy levels of trapped atoms (T_2 ~ 3s)
- Manipulation: excitation with laser pulses
- Trapped in optical lattices
- Interaction:
  - Collision
  - Rydberg-coupling



http://1.bp.blogspot.com

Trapped atoms

- Qubits: ions trapped in electric fields ($T_2 \sim$ 15s)
- Entanglement: spin coupling through harmonic oscillations
- Problem: entanglement of many ions
  $\longrightarrow$ photon coupling of small systems

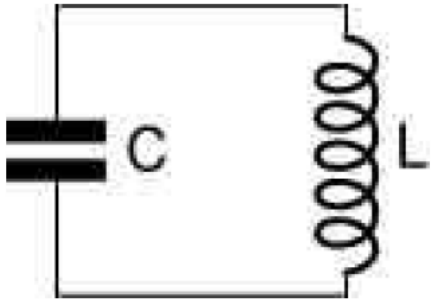


Quantum dots and dopants

- Quantum dots: bound elctrons in semi-conductor
- Dopants: P in Si binds one donator electron
- Qubit: orientation of electron spin
- Manipulation: electric and magnetic fields
- Coupling: exchange interaction

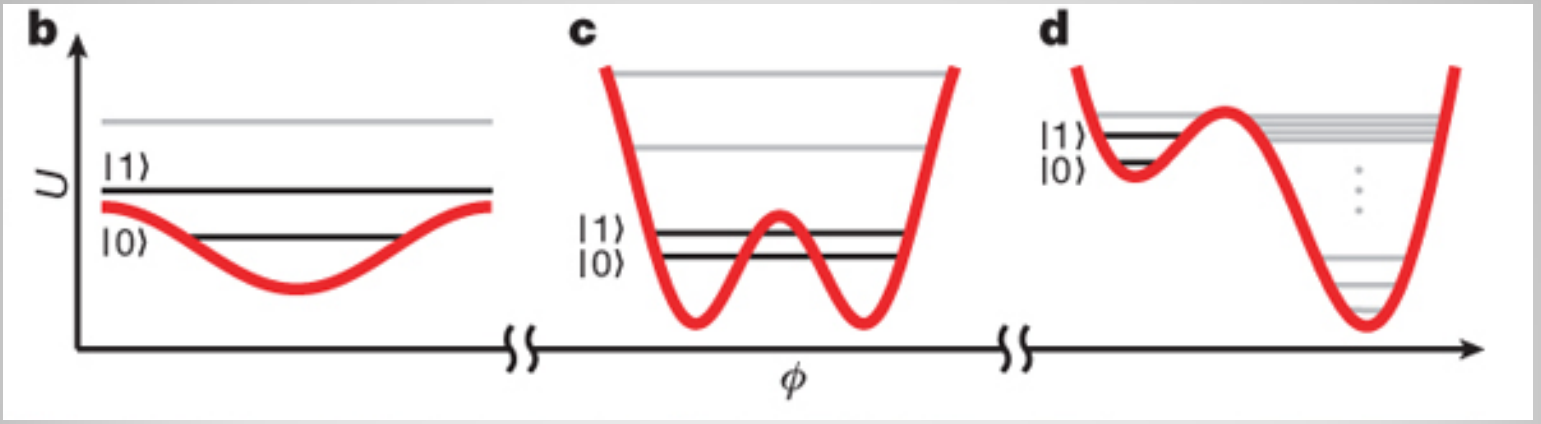
Superconductor

- Macroscopic quantum state ⟶ manipulation with classical devices (L and C)
- LC-resonator: harmonic oscillator with equidistant enery levels
- Qubits need non-linearities
  ⟶ josephson junction: anharmonic potential



Superconductor

- Charge Qubit
- Flux Qubit
- Phase Qubit



Outlook

- Fast QC: 100 entangled qubits
- Enlarge coherence time
- QEC