Quantum Computing with Trapped Ions

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Outline

• Quantum Computing
• Ion Trapping Theory
• Building a 493nm Laser
• Ion Trapping Experimental
The Quantum Advantage

\[ |\psi\rangle = \alpha |0\rangle + \beta |1\rangle \]

Classical Bit vs Qubit

Quantum Entanglement
Types of Qubits
Applications: According to IBMQ

The caffeine molecule
chemical name: 1, 3, 7-trimethylxanthine
chemical formula: C_{8}H_{10}N_{4}O_{2}

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ABC’s of Trapping an Ion

\[ \nabla \cdot E = \frac{\rho}{\varepsilon_0} \]

\[ E = -\nabla V \]

\[ \nabla^2 V = 0 \]

\[ \nabla^2 V = \nabla^2 \left( \frac{\alpha x^2}{2} + \frac{\beta y^2}{2} + \frac{\gamma z^2}{2} \right) \]

\[ = \alpha + \beta + \gamma \]

\[ = 0 \]

Static electric field =

\[ V = \frac{1}{2} (a x^2 + b y^2 + c z^2) \]
Pseudo-Potential

Time average is a minimum

[11]
Quadrupole / Paul Trap

[12]
Parabolic Mirror Ion Trap

[11]
Generated Pseudo-Potential

Trap architecture (not to scale)
Ionization Scheme

3P₁ ↝ 1S₀

337.1 nm

791 nm

∞

Excited State

Emitted Photon

Ground State
Cooling Cycle

$6P_{1/2} \rightarrow 5D_{3/2}$

493 nm

$6S_{1/2} \rightarrow 650$ nm

[11]
Doppler Cooling

[13]

[14]
Blue Light: Laser Diode (new!)

• Before in this lab: 986nm laser, doubling crystal
• Now: laser diodes
• PIN junction
Stimulated Emission

Absorption

Excited State

Absorbed Photon

Ground State

Spontaneous Emission

Excited State

Emitted Photon

Ground State

Stimulated Emission

Excited State

Emitted Photon

Ground State
External Cavity Diode Laser setup

1. External Cavity
2. 0-order
3. 1st order
4. Pivot point

[16]
Laser Setup
Temperature stabilization

• Thorlabs TED200C (4th attempt)
• Resistive Heater
• TEC
Laser modes
Temperature and Current Dependence
Laser Locking
Locking Scheme

Laser → PBS → HWP → 2x pass AOM → Cavity → PD → Feedback → Lock electronics
Ion trapping experimental Setup

Vacuum Chamber (trap)

Imaging Path (493 line filter, lens)

PMT

CCD Camera

[11]
Ion pictures

[11]
The Perfect Combination

- UV
- 493 nm
- 650 nm
- 791 nm

Barium (from oven)

Imaging path, lenses, out of page

= RF minimum
Searching for ions
Conclusion

• Ion trapping is non-trivial
• My laser allowed:
  • 2 orders of magnitude more power sent to the trap
  • Will allow better visualization of ions, less sensitive to frequency shifts
  • Wider section of space can be visualized
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Secular and Micro Motions

\[ x(t) = 2AC_0 \cos \left( \beta_x \frac{\omega_{rf}}{2} t \right) \left[ 1 - \frac{q_x}{2} \cos (\omega_{rf} t) \right] \]

\[ \beta_x = \sqrt{a_x + q_x^2} / 2, \]