What Atomic Physics has to offer for Quantum Computing

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6.UAT Proposal Talk

Spring 2008

Quantum Computing: (Brief) Inspiration

- Modern computing devices are based on classical mechanics (CM).

- But CM is a special limit of quantum mechanics.
  - *Conclusion*: Quantum devices can only have greater computational power than classical ones.

Quantum Computing: (Brief) Inspiration

- By a standard "complexity measure"…

Task	Quantum computational gains
Functional Iteration *f(f(…f(x)…)))*	Not sped up at all!
Locating an entry in a database of *N* entries	$O(N) \rightarrow O(N^{0.5})$
Prime factorization	Apparently, sped up exponentially!

Outline

1. **Requirements for a quantum computer**
2. Why atomic physics?
    1. Dilute gases in optical lattices
    2. Atom cooling
3. The next challenge.
4. Plan of action for our group.

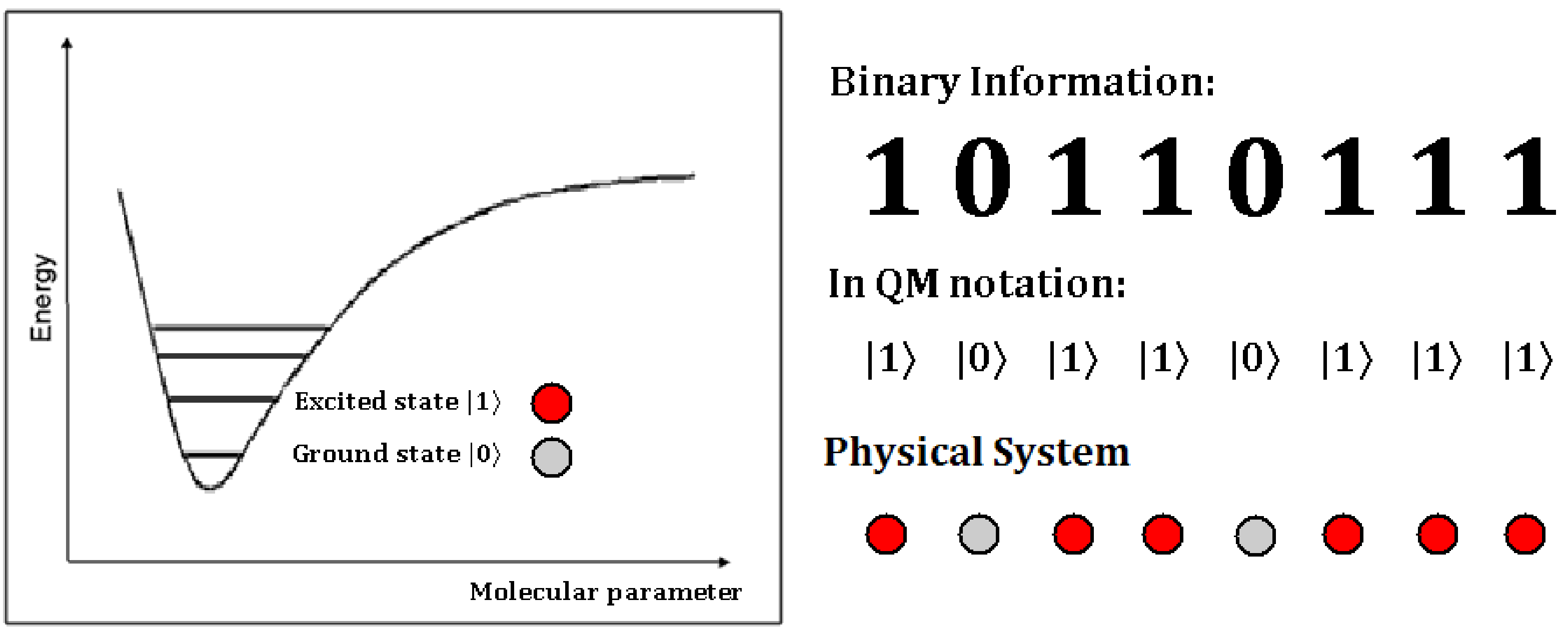
Basic Requirements for a Quantum Computer

1. **Scalable physical system with well-characterized qubits**
2. **The ability to initialize the state of the qubits**
3. Long decoherence times
4. Universal set of quantum gates
5. **A qubit-specific measurement capacity**
6. Ability to transport qubits

Source: DiVincenzo, David P. "The Physical Implementation of Quantum Computation." Fortschritte der Physik.

1) "Scalable physical system with well-characterized qubits"

- *Qubit*: A two-level physical system.
  - e.g. ground and excited states of an atom.

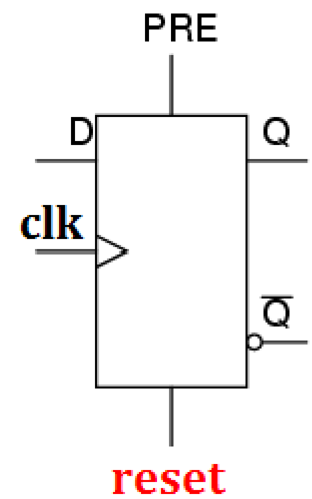


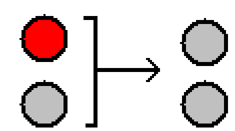
- Use two-level system to encode binary information.

2) "Ability to initialize the state of the qubits"

- Clearly necessary for information processing.

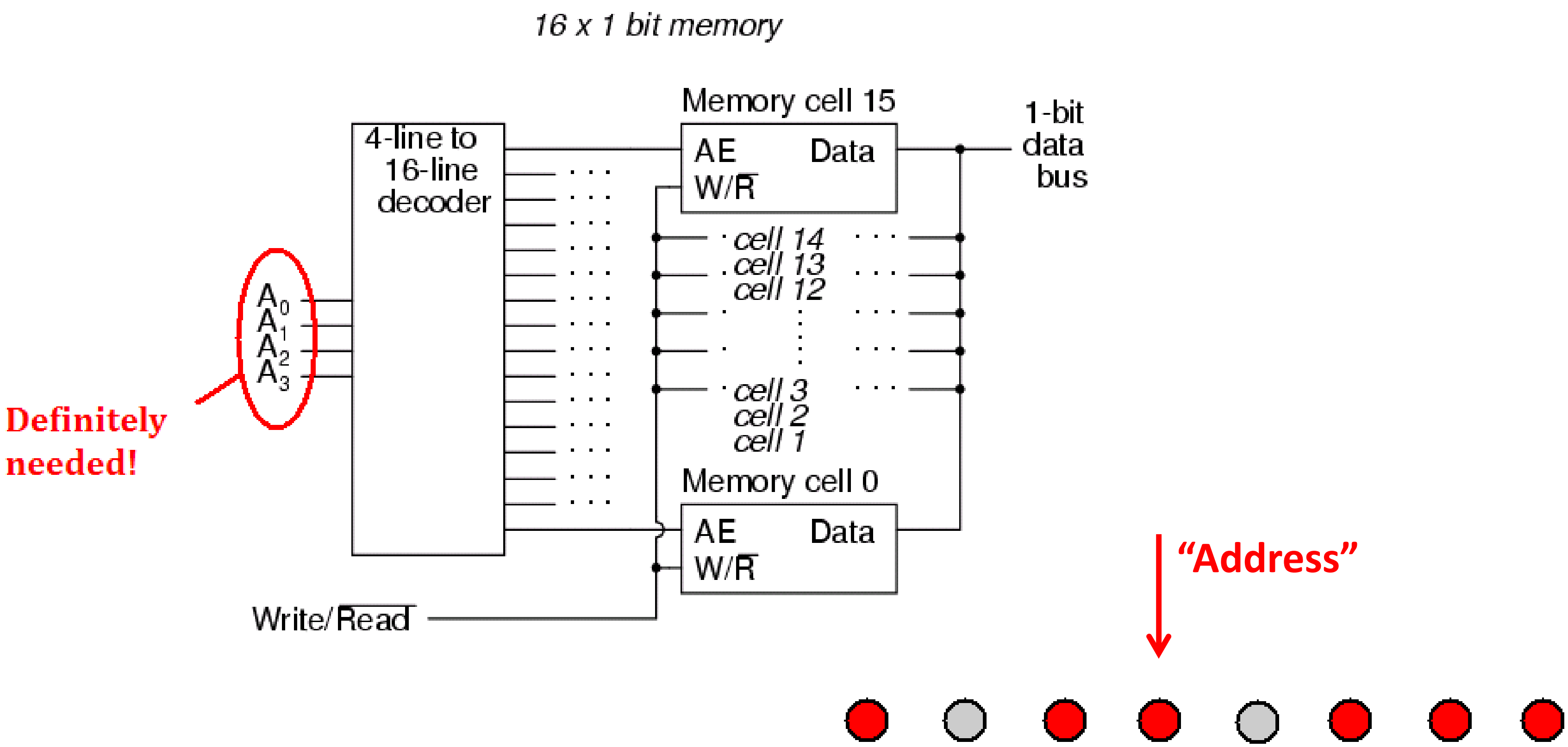
- For example, suppose we want to *reset all qubits*.
  - Physically, we need a way to manipulate many qubits *en masse*.





3) “A qubit-specific measurement capacity”

- Need a reliable way to access information.
- Must allow for specific addressing of the physical element.



Summary of the Problem

- Quantum computing demands:
  - A scalable physical system with two states
  - Ability to initialize the macroscopic system
  - Qubit-specific measurement capacity

- Proposal:
  - *Dilute gases* found in atomic physics labs are an ideal system meeting the above requirements.

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2. **Why atomic physics?**
    1. **Dilute gases in optical lattices**
    2. **Atom cooling**
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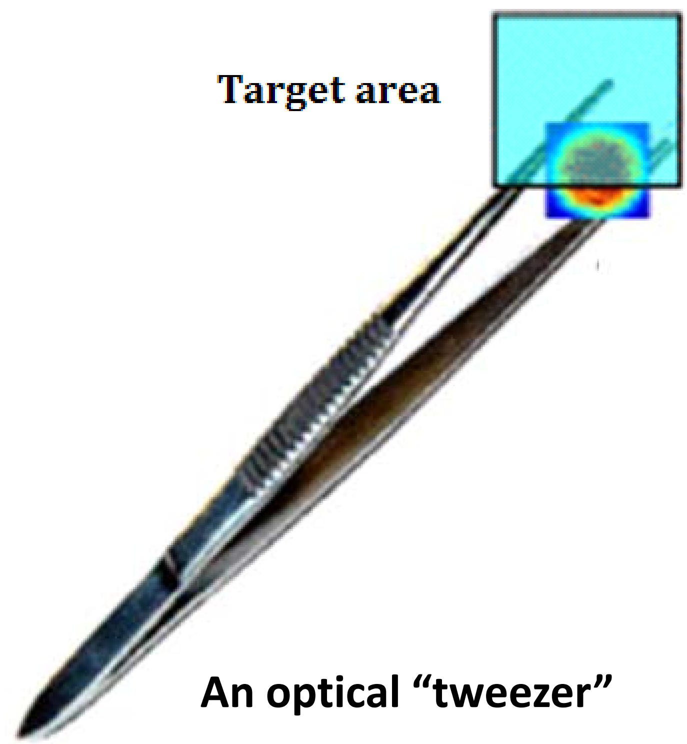
Why atomic physics?

- Precision.



Atomic physics: an illustrious recent history

- Development of precise, atomic physics techniques have led to several recent Nobel prizes.

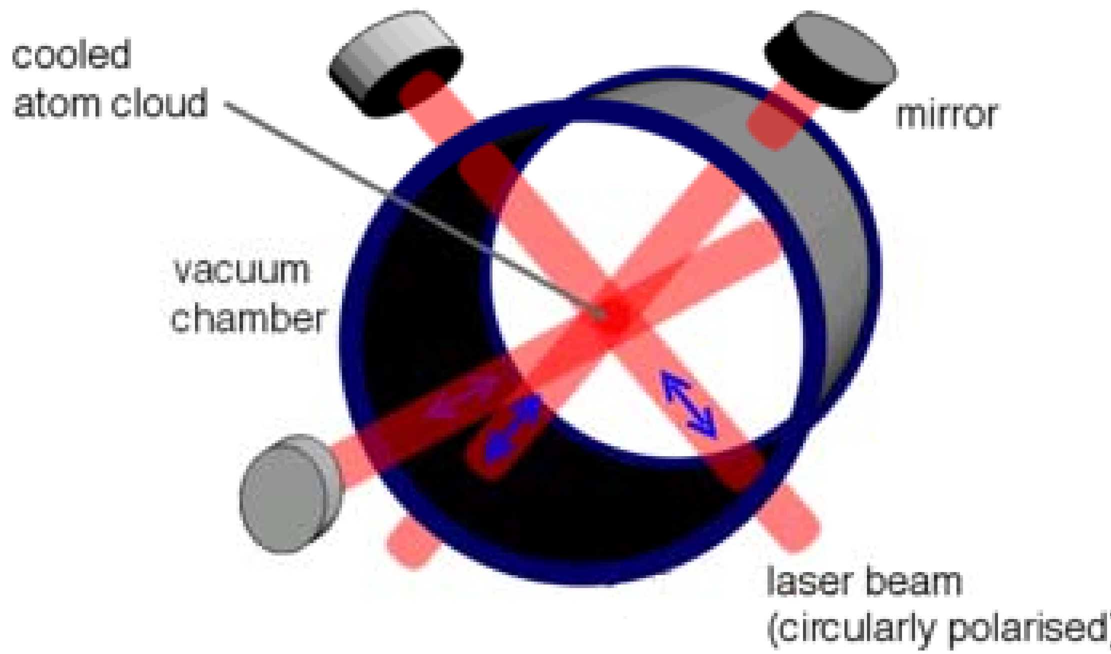
  - 1997 – Chu, Cohen-Tannoudji, Phillips: “For development of **methods to cool and trap atoms with laser light**.”

  - 2001 – Cornell, Ketterle, Wieman: “For the achievement of Bose-Einstein condensation in dilute gases of alkali atoms…”

  - 2005 – Hall, Haensch: “For their contributions to the development of laser-based precision spectroscopy, including the **optical frequency comb technique**.”

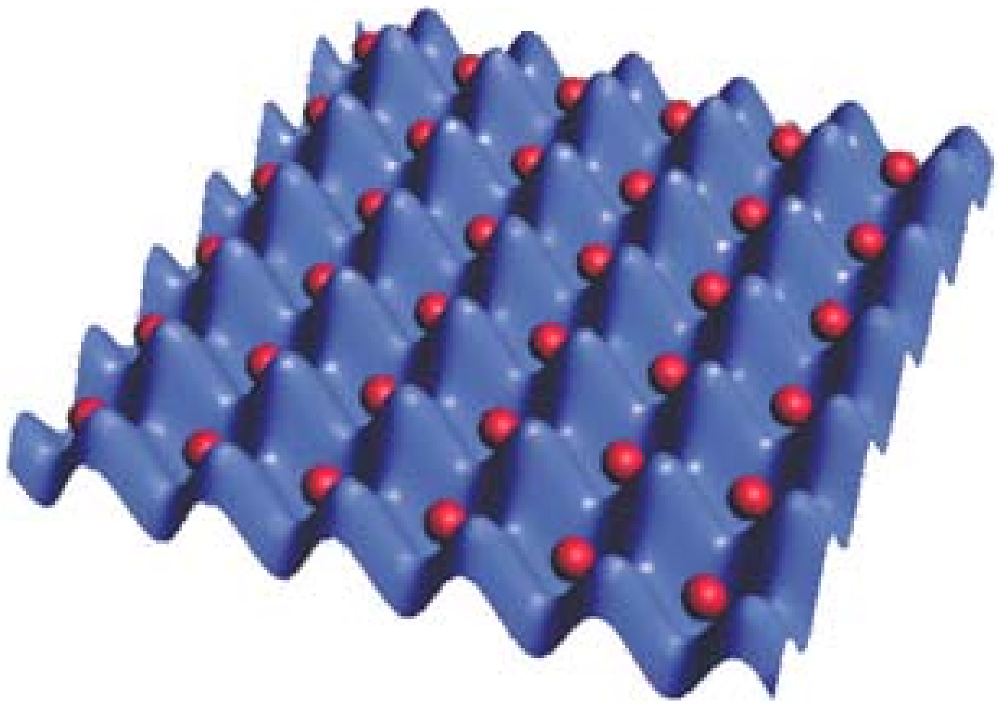
Dilute gases in an optical lattice

- Chu, C-T, Phillips (1997)
  - Begin by setting up a standing wave



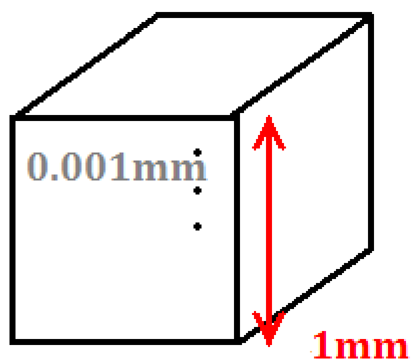
Dilute gases in an optical lattice

- Neutral atoms are attracted to regions of high oscillating electric field (*"ac Stark effect")*.



Dilute gases in an optical lattice: Typical numbers

- We routinely produce: *~1 million atoms* per run.
- Our optical lattice is based on infrared laser*: λ = 1000 nm*
- The overlap volume of the lattice beams is: *~(1mm)^3*



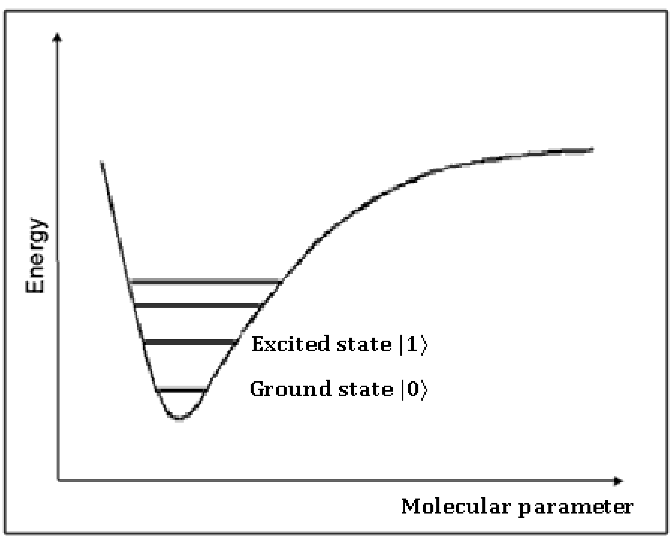
Number of sites:
N = 1,000,000

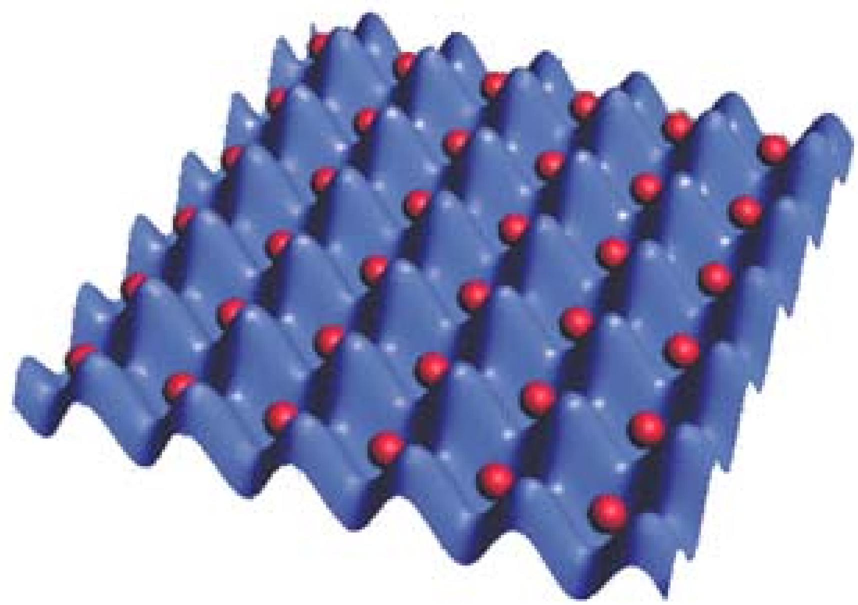
Approximately one atom per site!

- So, one atom per site is a realistic scenario!

A Scalable QM System

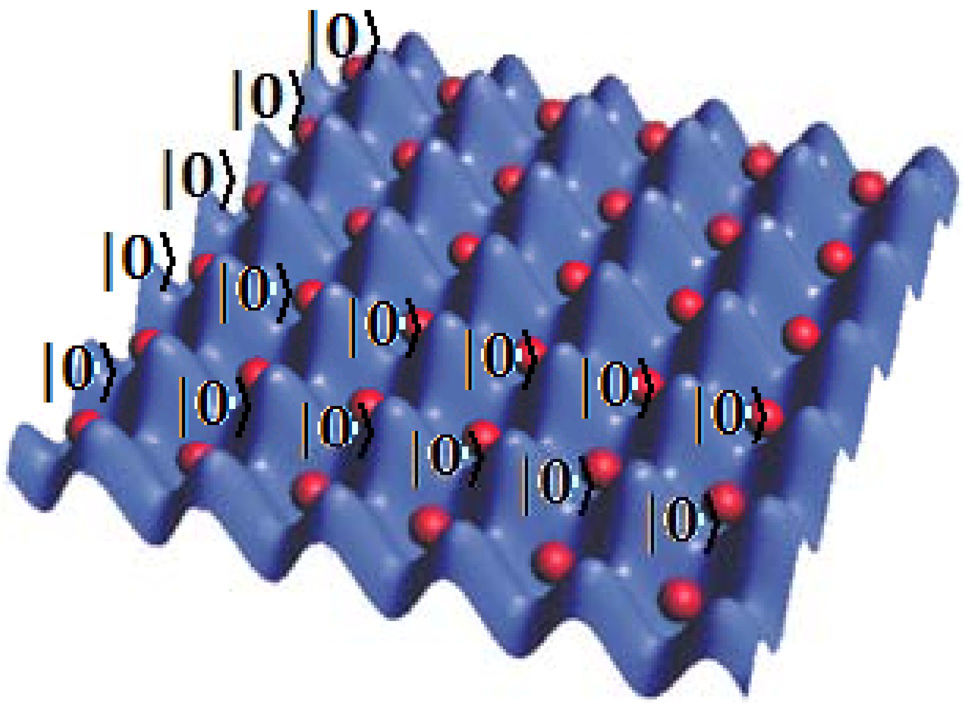
- Atomic physics quantum computer:
  - Excited atomic/molecular states in optical lattice
  - **As of now, we can create such experimental setups routinely.**
    - We possess dual-species oven: sodium and lithium





Resetting all qubits: atom cooling

- Decades of experience in cooling atoms
  - Remove thermal energy → Favor the ground state.



Summary of Previous Work

- The current state of atomic physics gives:
  - A readily scalable platform for qubits. (Requirement 1)
  - Easy to initialize to the “reset state.” (Requirement 2)

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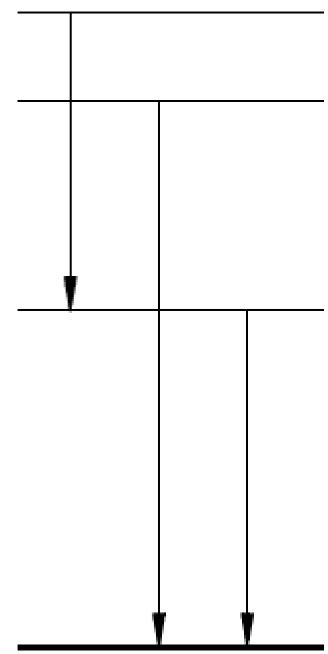
A qubit-specific measurement capacity

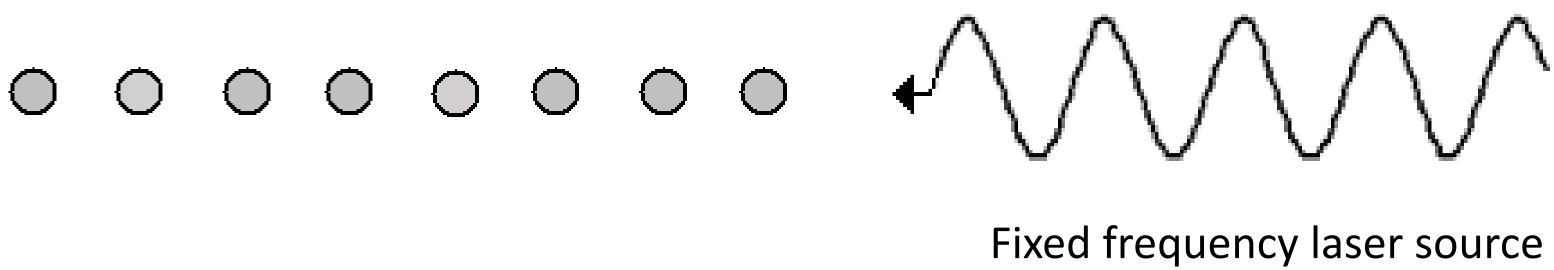
- We now have qubits in a known geometry.
- How to manipulate individual qubits?

- Proposal:
  - Use light-induced transitions.



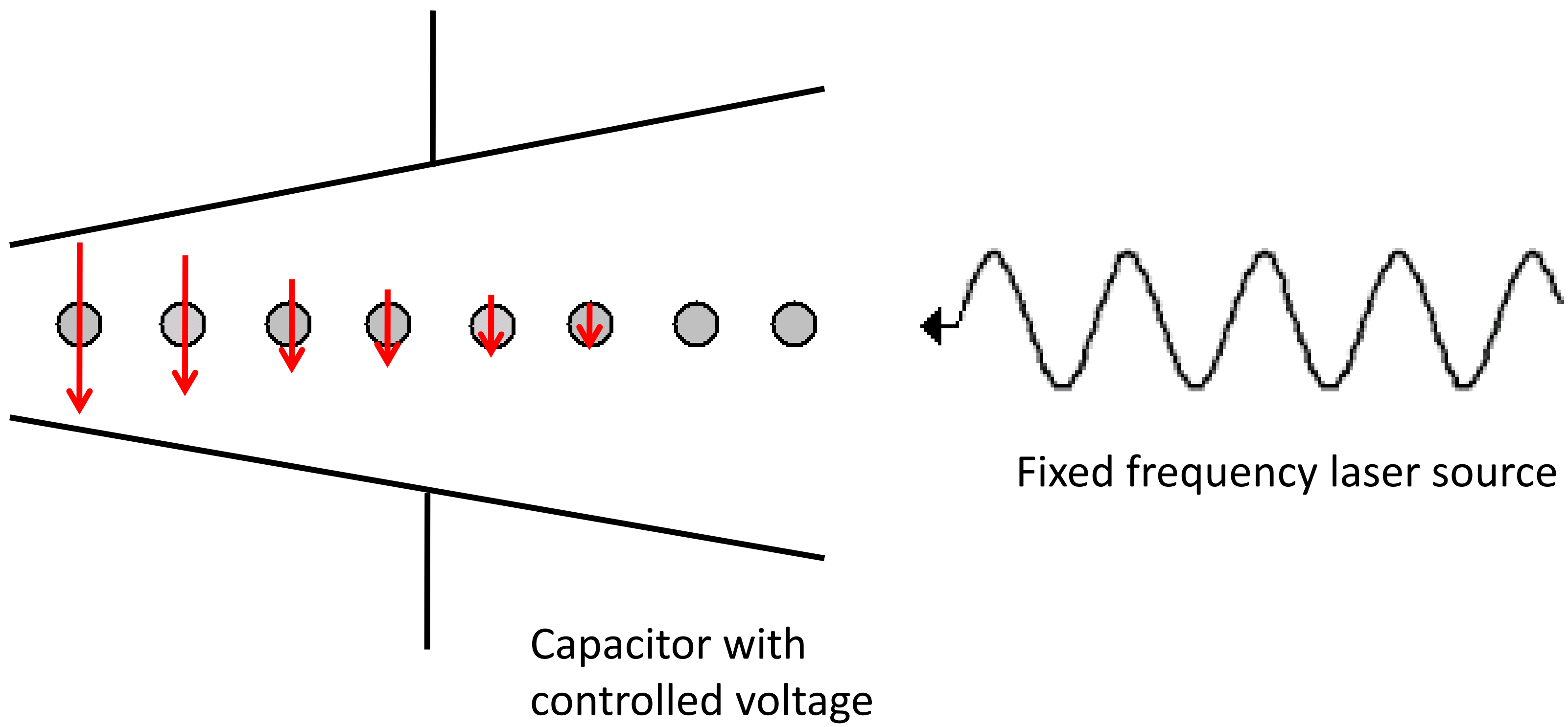
Light induced transitions in an optical lattice

- Consider the 1D array of qubits:
  - With a fixed wavelength laser source, tuned to atomic transition



Light induced transitions in an optical lattice

- Laser frequency is fixed.
  - Instead, tune the atoms → Modify the atomic energy spacing.



What needs to be done

- E-Field modification of energy levels depends on *electric dipole* of the qubit.

- Our task:
  - Produce a molecule with a permanent dipole moment.
  - For our group, that means:
  - **Production of sodium-lithium molecule.**

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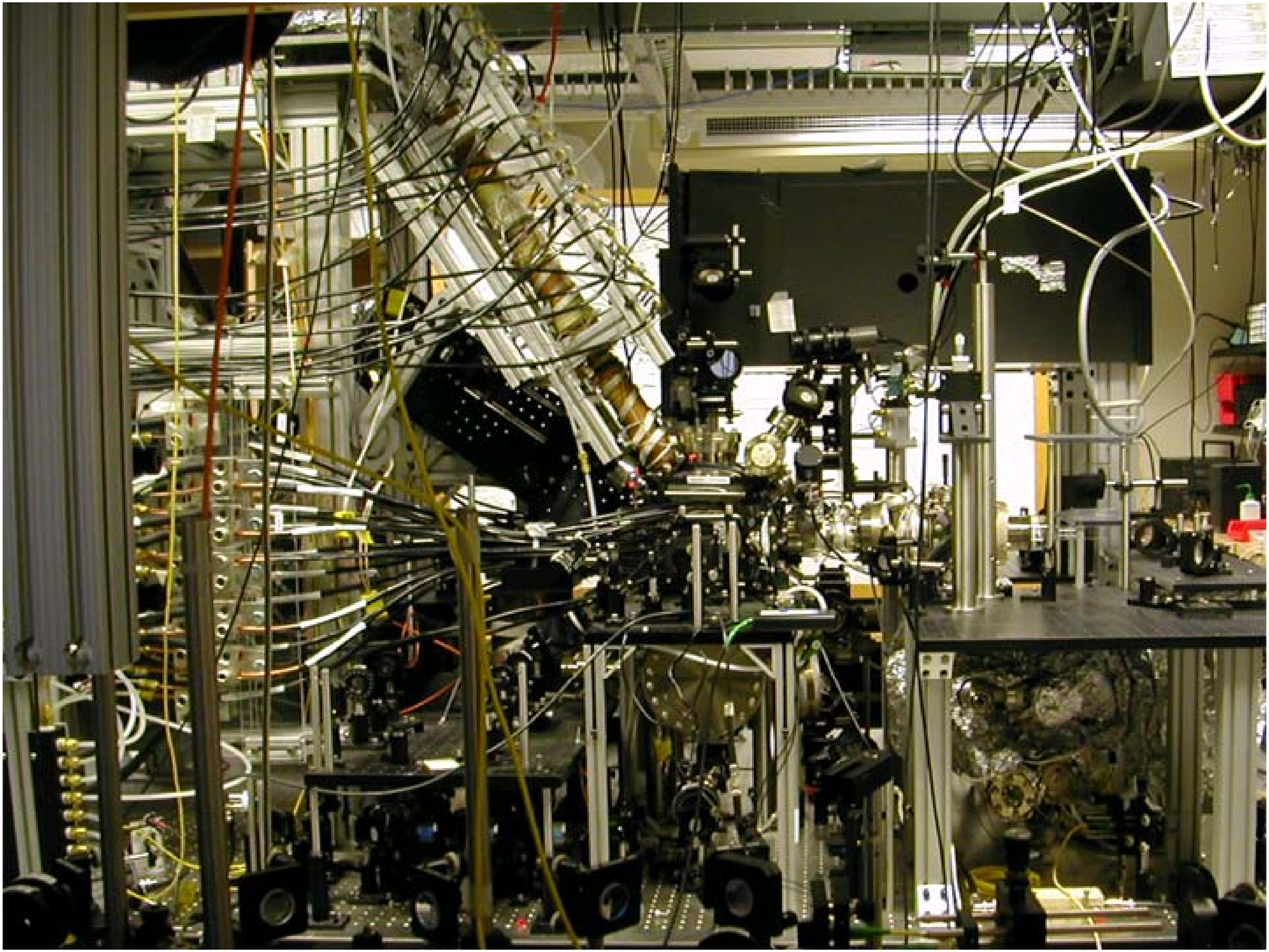
Calendar

- Early summer 2008:
  - Installation of the optical lattice chamber.
- Summer 2008:
  - Settle the lab’s temperature problem.
  - Reinstallation of the optics/electronic equipment.



Calendar (continued)

- Fall 2008:
  – Association of lithium and sodium atoms.
- Sometime further on:
  – Attain deeply bound lithium and sodium atoms.