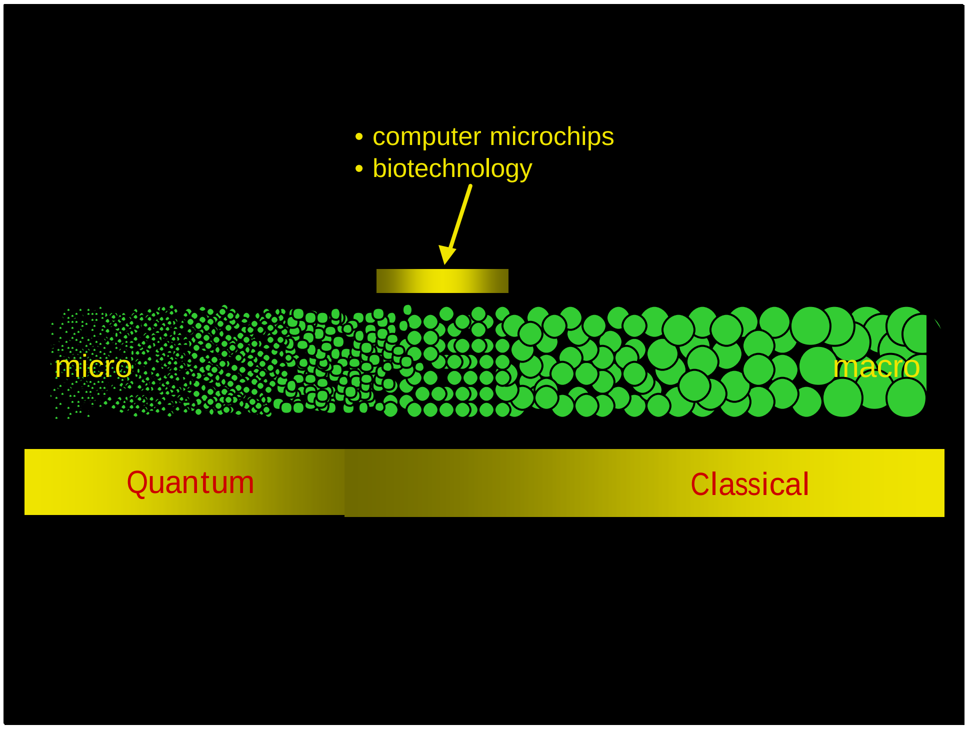
“Experimental quantum computers”

1 – Qubits in context

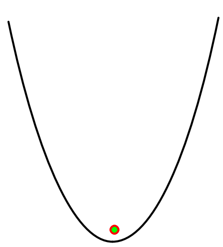
Hideo Mabuchi, Caltech Physics and Control & Dynamical Systems
hmabuchi@caltech.edu http://minty.caltech.edu/MabuchiLab/

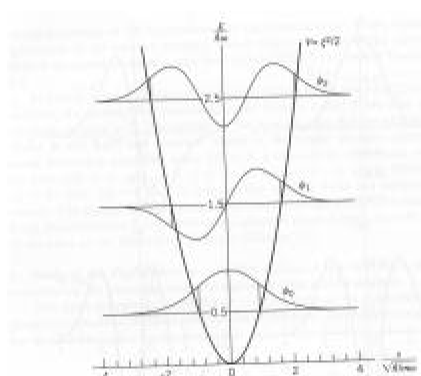
- Why all the fuss?
- Where are we at?
- Where do we go from here?

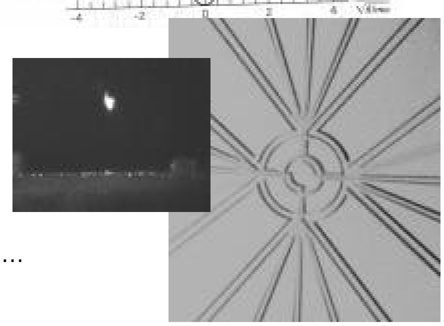
1. **Qubits in context – quantum mechanics and natural phenomena**
   1. Microphysics and macrophysics; size and energy scales ($\hbar\omega$ vs. kT)
   2. Issues of the quantum-classical “interface”
   3. Closed vs. open systems, coherence timescales
   4. Physical requirements for *large-scale* quantum computing
   5. A very brief survey of physical systems with quantum behavior
2. **A crash course in real-world quantum mechanics**
   1. States and measurement: differences from classical physics
   2. Dynamics via the Schrödinger Equation; discrete maps
   3. Open systems, statistical mechanics, decoherence
   4. Realistic equations for an experimental system
   5. Whence come the qubits?
   6. Benefits and penalties of computational abstraction
3. **Implementations, Part 1: oldies but goodies**
   1. Photons, quantum phase gate, Kimble *et al.*
   2. Ion trap quantum computing, Wineland/Monroe, quantum “abacus”
   3. NMR ensemble quantum computing, Chuang *et al.*, pros and cons
4. **Implementations, Part 2: new and fashionable**
   1. Kane proposal, Clark project
   2. Superconducting qubits, Devoret experiment
   3. Neutral atoms in optical lattices, Bloch experiment, addressing
   4. Continuous variables, spin squeezing, Polzik experiment



Classical harmonic oscillator







• point particle in quadratic potential

• “state” $ {x(t),p(t)}

• oscillation frequency $\omega=[k/m]^{1/2}$

• *e.g.* mass on a spring, rolling marble, …

Microphysics and macrophysics, size and energy scales

- We can identify quantum and classical limits in size, energy
- Intermediate regime – the regime of interest – is relatively murky
- ~ω indicates energy scale of quantization
- kT is a thermal energy spread
- ~ω/kT is a rough figure-or-merit for "quantumness"

Issues of the quantum—classical "interface"

- Notion of quantum state, quantum phenomenology
- Incompatibility with classical phenomenology
- The measurement "problem," interpretations thereof
- Necessity (and difficulty!) of preserving "un-collapsed" states
- Q-C transition is robust) Q. computing requires pathological configurations!

Closed vs. open systems, coherence timescales

- Conservation laws, reversibility imply *leakage* of information » measurement
- Timescale for imprinting » decoherence timescale

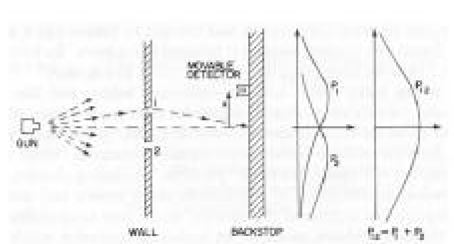
Physical requirements for *large-scale* quantum computing

- Recall, benefits of quantum computing emerge "asymptotically"
- Physical system with controllable and observable (?) sub-space
- "Long" coherence times
- Scalability
  - Physical extensibility
  - Mechanism for suppression of "errors"

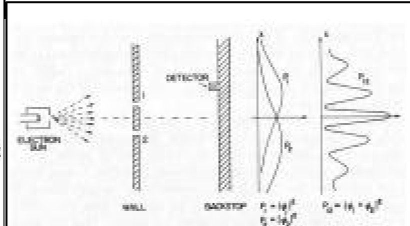
Physical systems with quantum "behavior," and technology

- Coherent superposition, interference: interferometers, atomic clocks
- Tunneling: alpha decay, solid-state tunnel junctions (intentional, or not!)
- Superconductors: persistent currents, SQUID magnetometers
- Superfluids: liquid helium, degenerate atomic gases
- Entanglement: Bell Inequality violations, teleportation

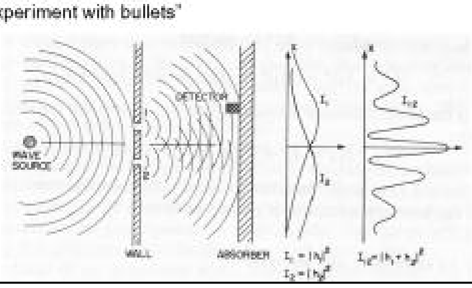
Interferometers (double-slit)

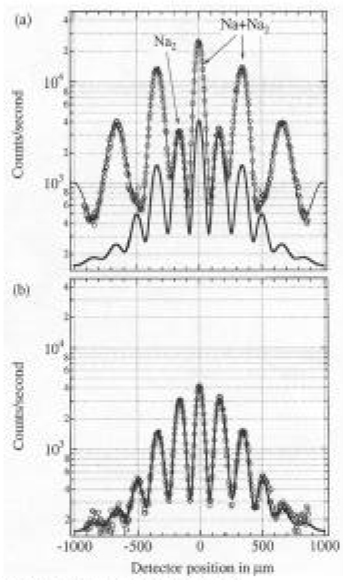


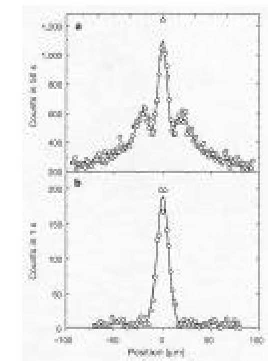
Leighton, and Sands, *The Feynman Lectures on Physics V*
y, 1965)]
experiment with bullets"



e 1-3: "An experiment with electrons"







[M. S. Chapman *et al*, Phys. Rev. Lett. **74**, 4783 (1995)]