Title: PSI 17/18 - Quantum Information - Lecture 3

Date: Feb 22, 2018 11:30 AM

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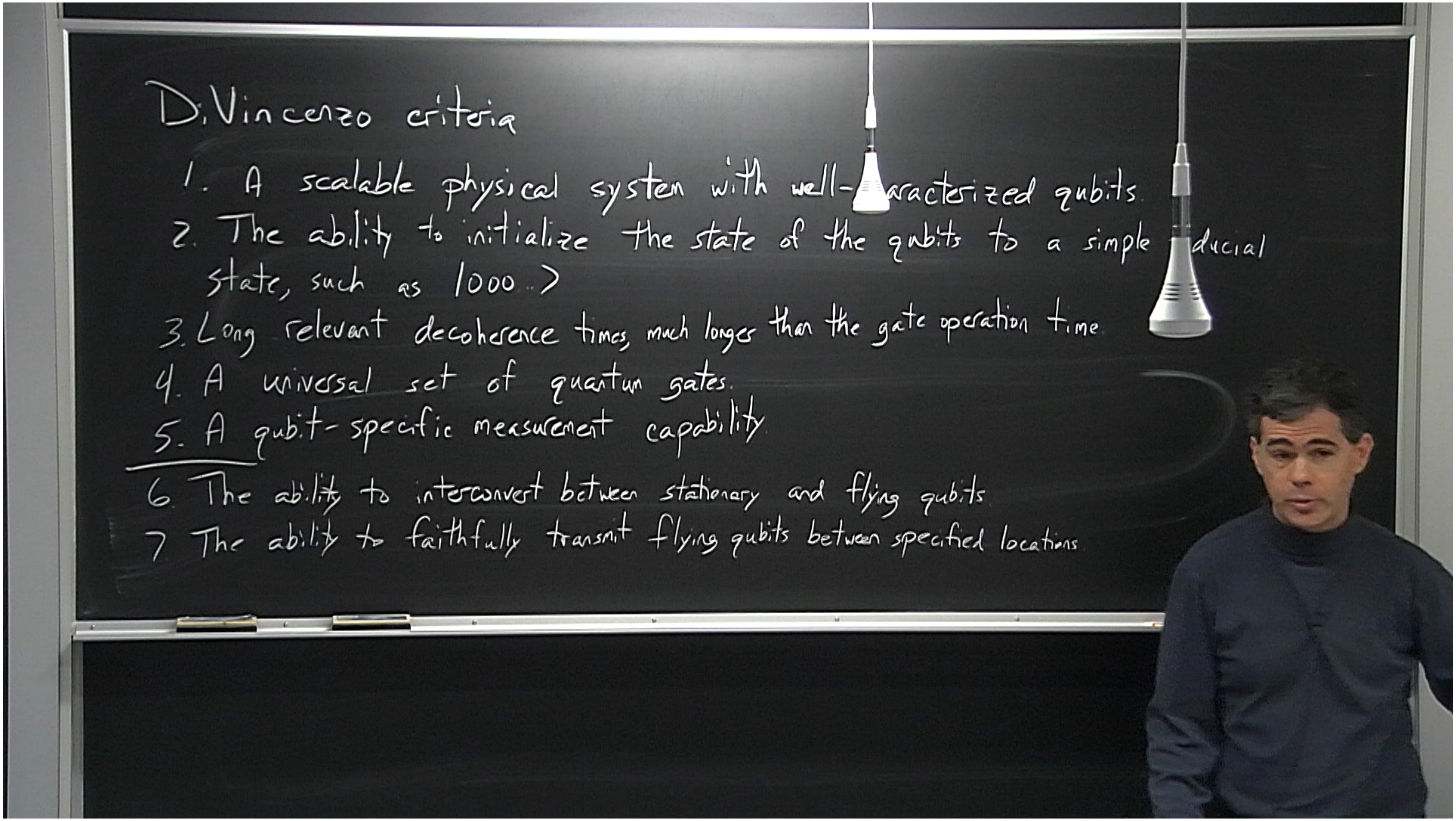
Abstract:

DiVincenzo criteria

1. A scalable physical system with well-characterized qubits.
2. The ability to initialize the state of the qubits to a simple fiducial state, such as $|000...\rangle$
3. Long relevant decoherence times, much longer than the gate operation time.


DiVincenzo criteria
1. A scalable physical system with well- aracterized qubits
2. The ability to initialize the state of the qubits to a simple ducial state, such as |000...⟩
3. Long relevant decoherence times, much longer than the gate operation time
4. A universal set of quantum gates.
5. A qubit-specific measurement capability
6. The ability to interconvert between stationary and flying qubits
7 The ability to faithfully transmit flying qubits between specified locations

5. A qubit-specific measurement capability

6. The ability to interconvert between stationary and flying qubits

7. The ability to faithfully transmit flying qubits between specified locations

Ion traps:

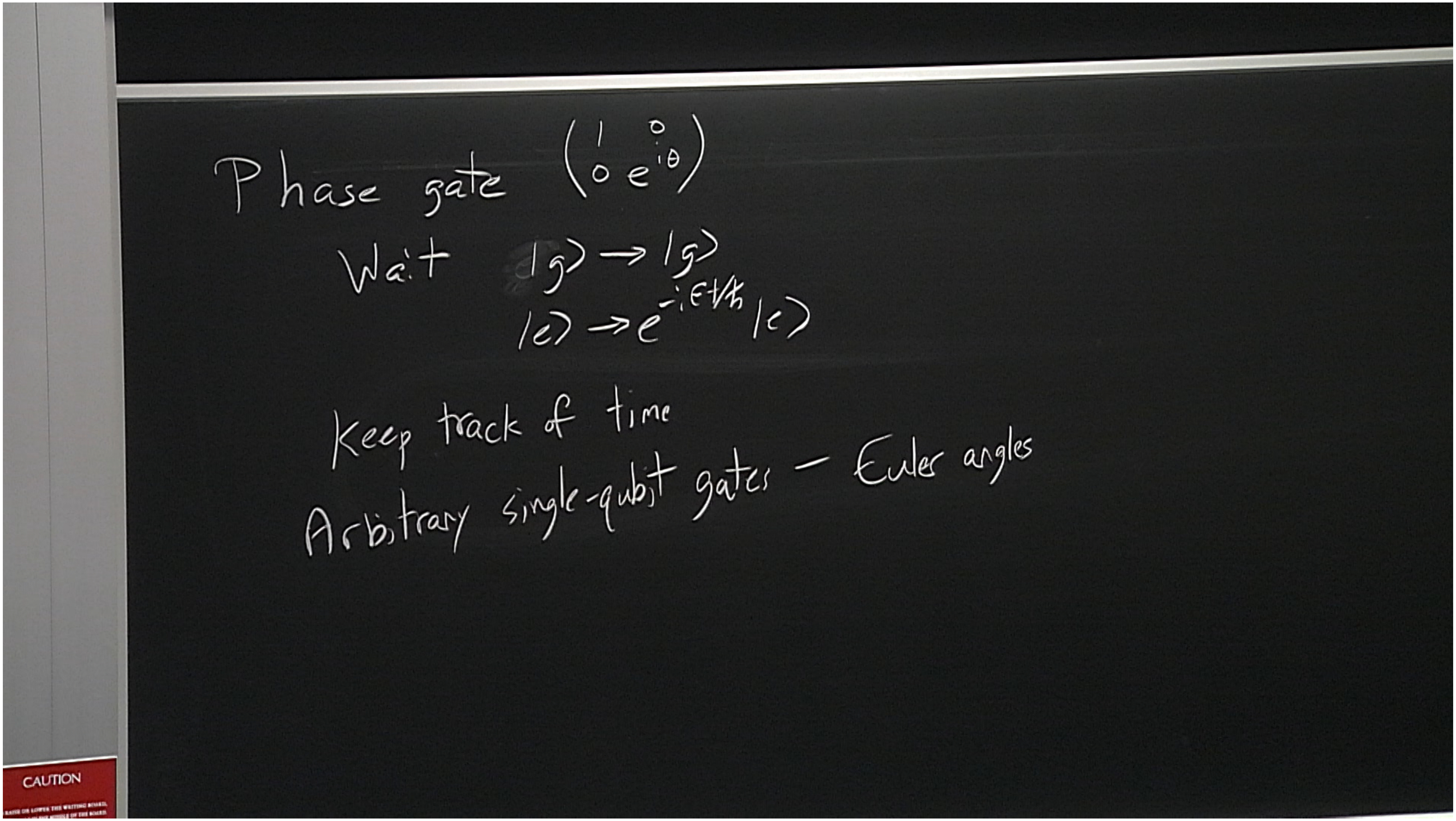
Qubit is an atom, usually group II, ionized once ⇒ One outer shell electron

Ground state $|g\rangle = |0\rangle$

Excited state $|e\rangle = |1\rangle$

$$H = H_{atom} + H_{laser} = \epsilon |e\rangle\langle e| + J\left(e^{-i\omega t}|g\rangle\langle e| + e^{i\omega t}|e\rangle\langle g|\right)$$

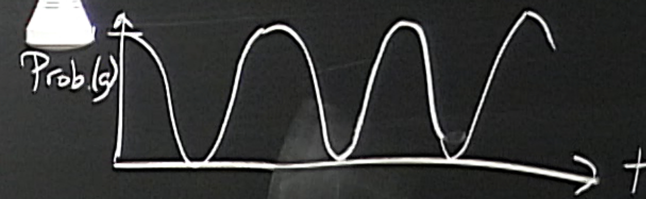
laser with frequency $\omega = \epsilon/\hbar$

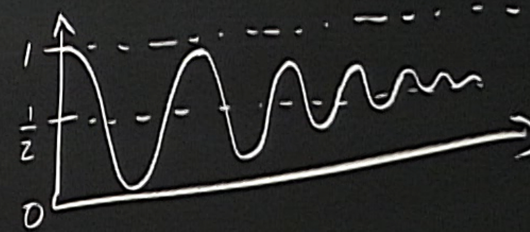

Phase gate $\begin{pmatrix} 1 & 0 \\ 0 & e^{i\theta} \end{pmatrix}$
Wait $|g\rangle \to |g\rangle$
$|e\rangle \to e^{-iEt/\hbar}|e\rangle$
Keep track of time
Arbitrary single-qubit gates – Euler angles
CAUTION

Ideally, we get (when the laser is on)

$$|g\rangle \longmapsto \cos\left(\frac{Jt}{\hbar}\right)|g\rangle + \sin\left(\frac{Jt}{\hbar}\right)|e\rangle$$

Rabi oscillation





In ion traps, 10^4 or more oscillations before decay.

$\Rightarrow$ condition 3.

$\pi/2$ pulse $\Rightarrow$ bit flip.

$\pi/4$ pulse $\Rightarrow$ Hadamard

π $\Rightarrow$ -1 global phase

Phase gate $\begin{pmatrix} 1 & 0 \\ 0 & e^{i\theta} \end{pmatrix}$

Wait $|g\rangle \rightarrow |g\rangle$

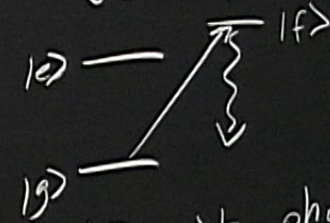
$|e\rangle \rightarrow e^{-i\epsilon t/\hbar}|e\rangle$

Keep track of time

Arbitrary single-qubit gates — Euler angles

Measurement:

Use $|f\rangle$ which is short-lived



gf transition

$|f\rangle$ emits photons — can be seen

$|g\rangle$ cycles to $|f\rangle$

$|e\rangle$ does nothing — dark.

$\Rightarrow$ conditions 5 & 2

Use an additional state $|e'\rangle$ w/ energy ϵ'

Let $\omega' = (\epsilon' - \epsilon)/\hbar - \nu$

Cirac-Zoller gate: Start w/ phonon in $|0\rangle_p$

1. Do a $\pi/2$ pulse on ion 1 w/ freq. ω

$|g\rangle_1 |0\rangle_p \rightarrow |g\rangle_1 |0\rangle_p$
$|e\rangle_1 |0\rangle_p \rightarrow |g\rangle_1 |1\rangle_p$

2. Do a π pulse on ion 2 w/ freq. ω'

$|g\rangle_2 |0\rangle_p \rightarrow |g\rangle_2 |0\rangle_p$
$|e\rangle_2 |0\rangle_p \rightarrow |e\rangle_2 |0\rangle_p$
$|g\rangle_2 |1\rangle_p \rightarrow |g\rangle_2 |0\rangle_p$
$|e\rangle_2 |1\rangle_p \rightarrow -|e\rangle_2 |1\rangle_p$

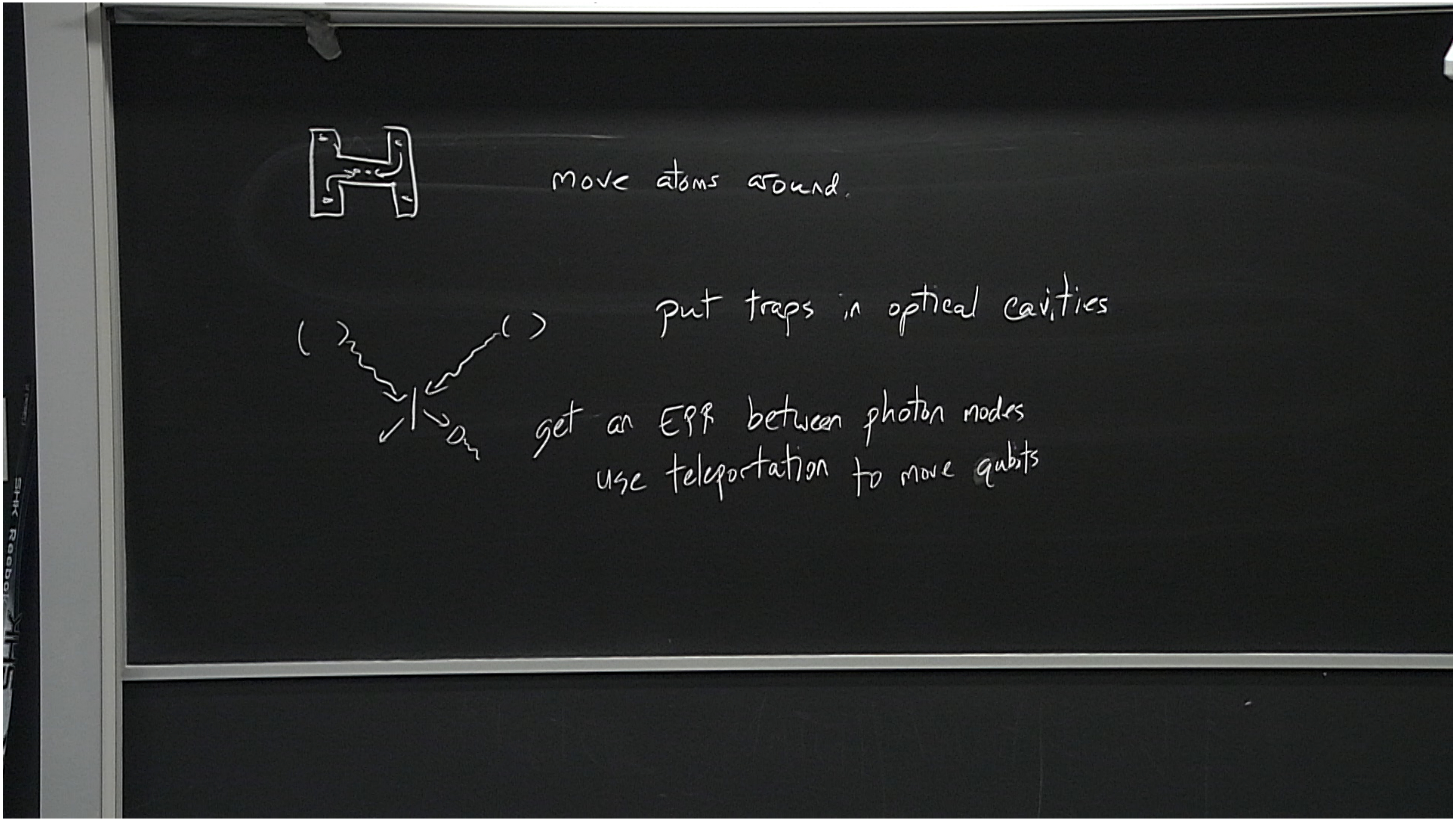
3. Undo step 1

Overall effect is C-phase gate

$|g\rangle_1 |g\rangle_2 \rightarrow |g\rangle_1 |g\rangle_2$
$|g\rangle_1 |e\rangle_2 \rightarrow |g\rangle_1 |e\rangle_2$
$|e\rangle_1 |g\rangle_2 \rightarrow |e\rangle_1 |g\rangle_2$
$|e\rangle_1 |e\rangle_2 \rightarrow -|e\rangle_1 |e\rangle_2$

$$\begin{pmatrix} 1 & & & 0 \\ & 1 & & \\ & & 1 & \\ 0 & & & -1 \end{pmatrix}$$

Universal $\Rightarrow$ conditions


move atoms around.
put traps in optical cavities
get an EPR between photon modes
use teleportation to move qubits