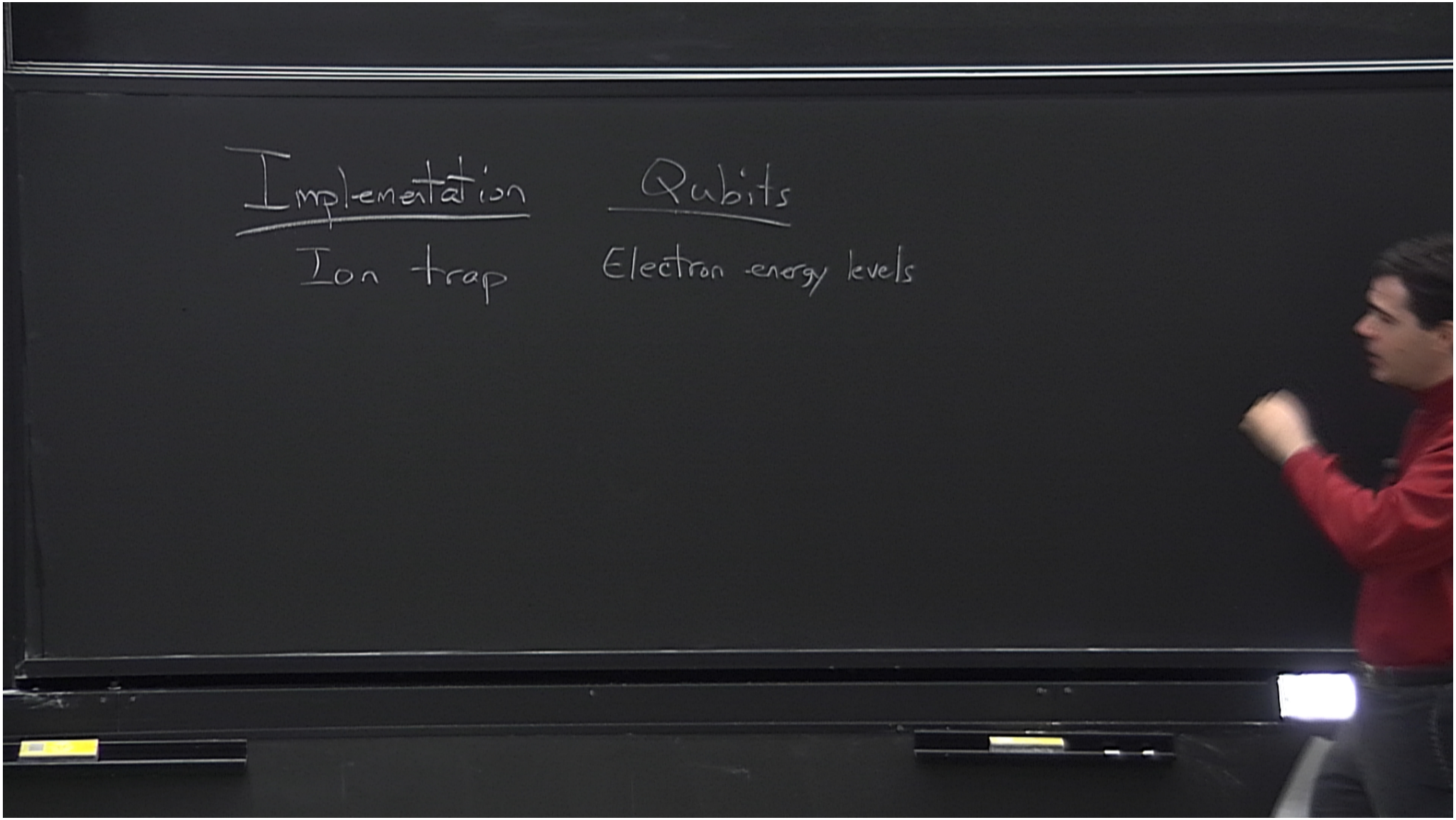
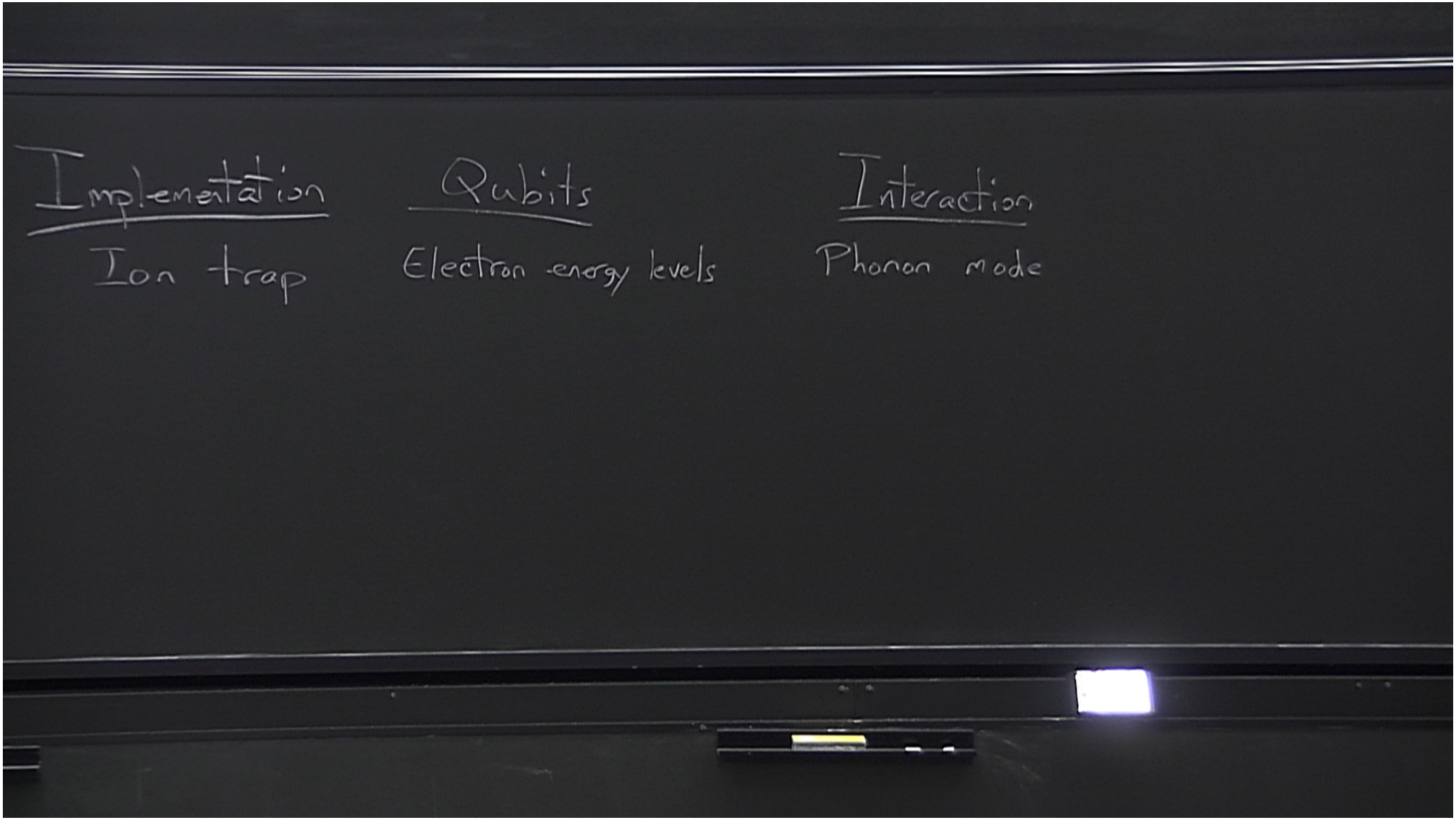
Title: Quantum Information (Review) - Lecture 4

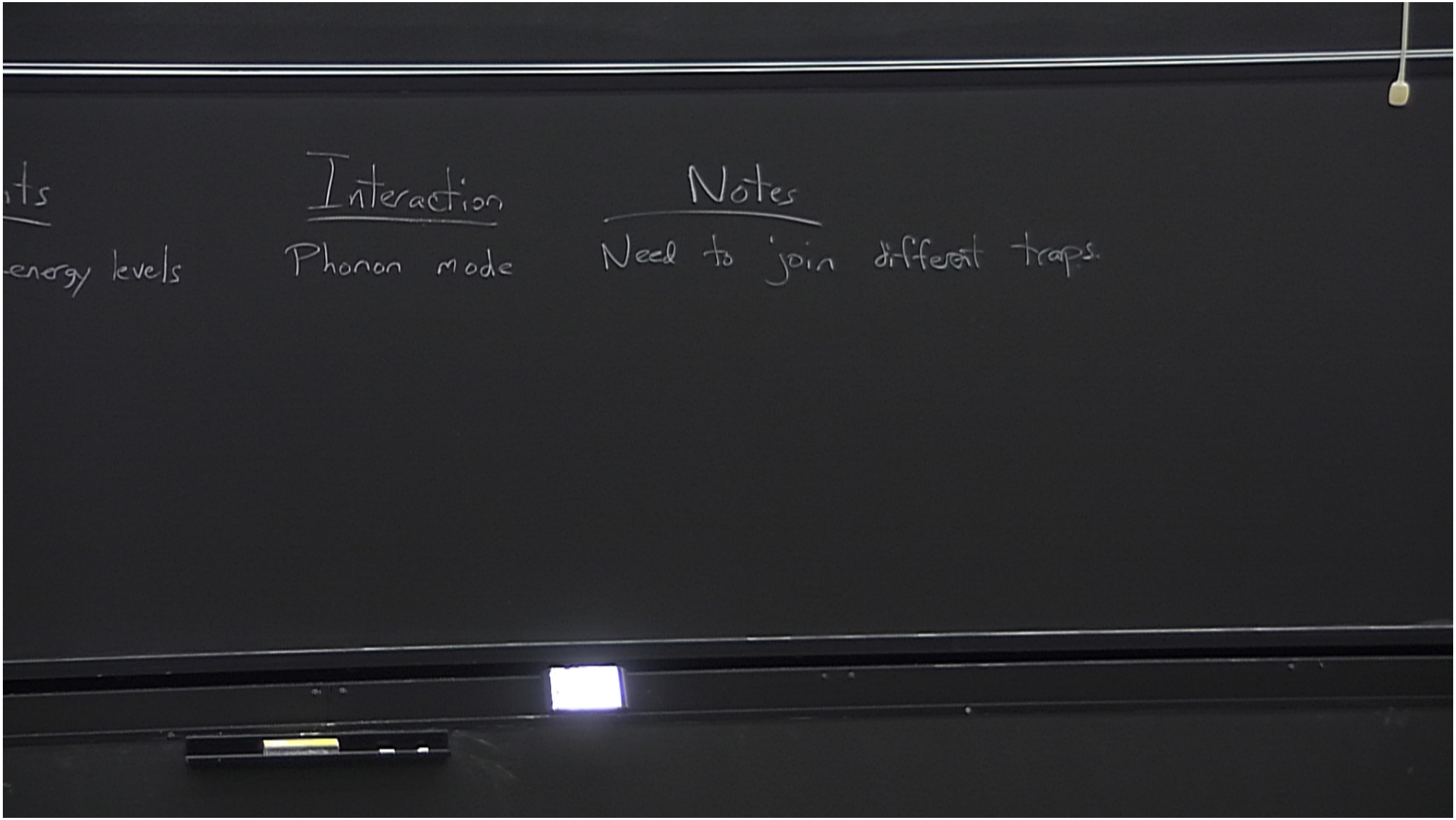
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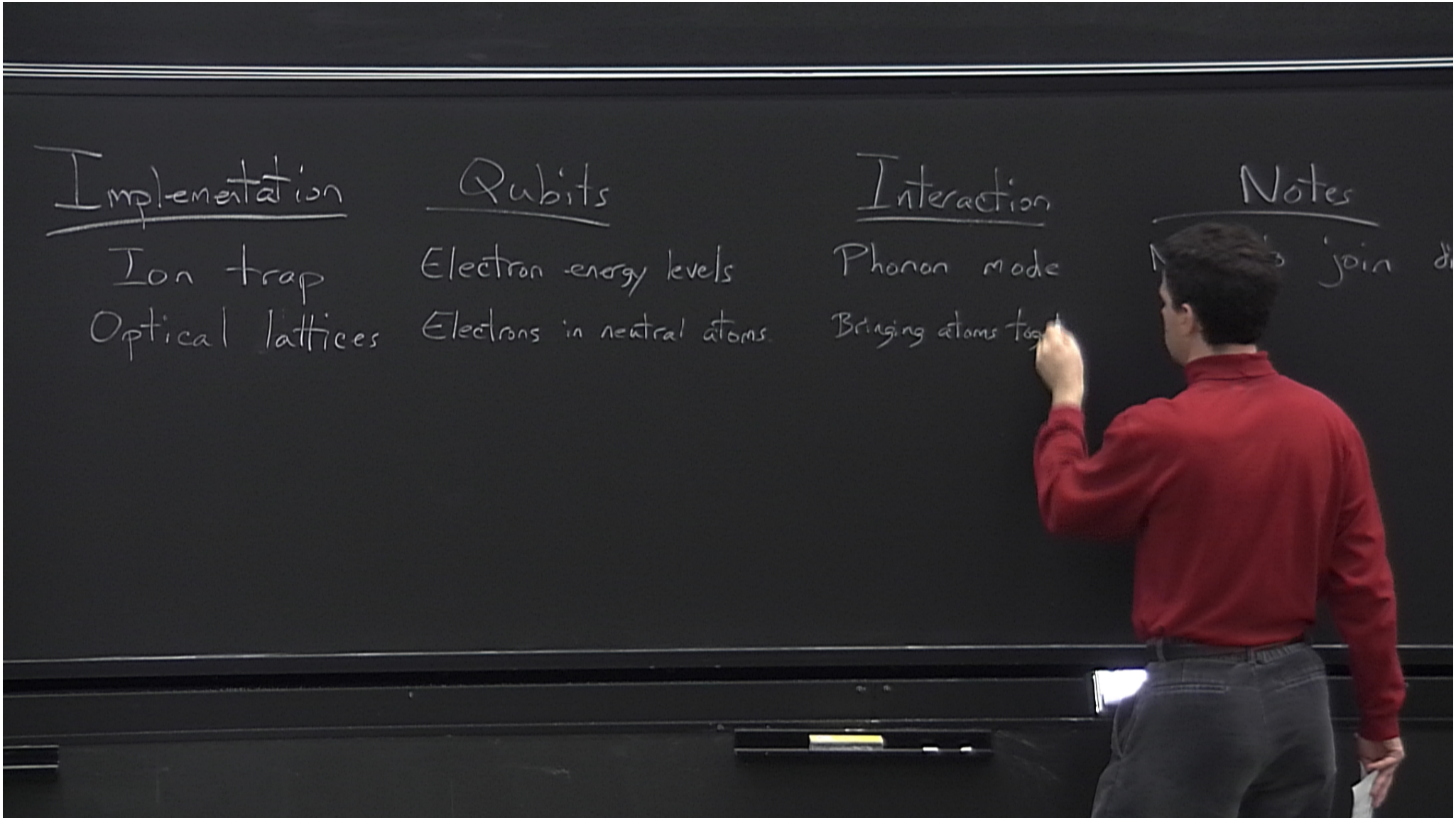
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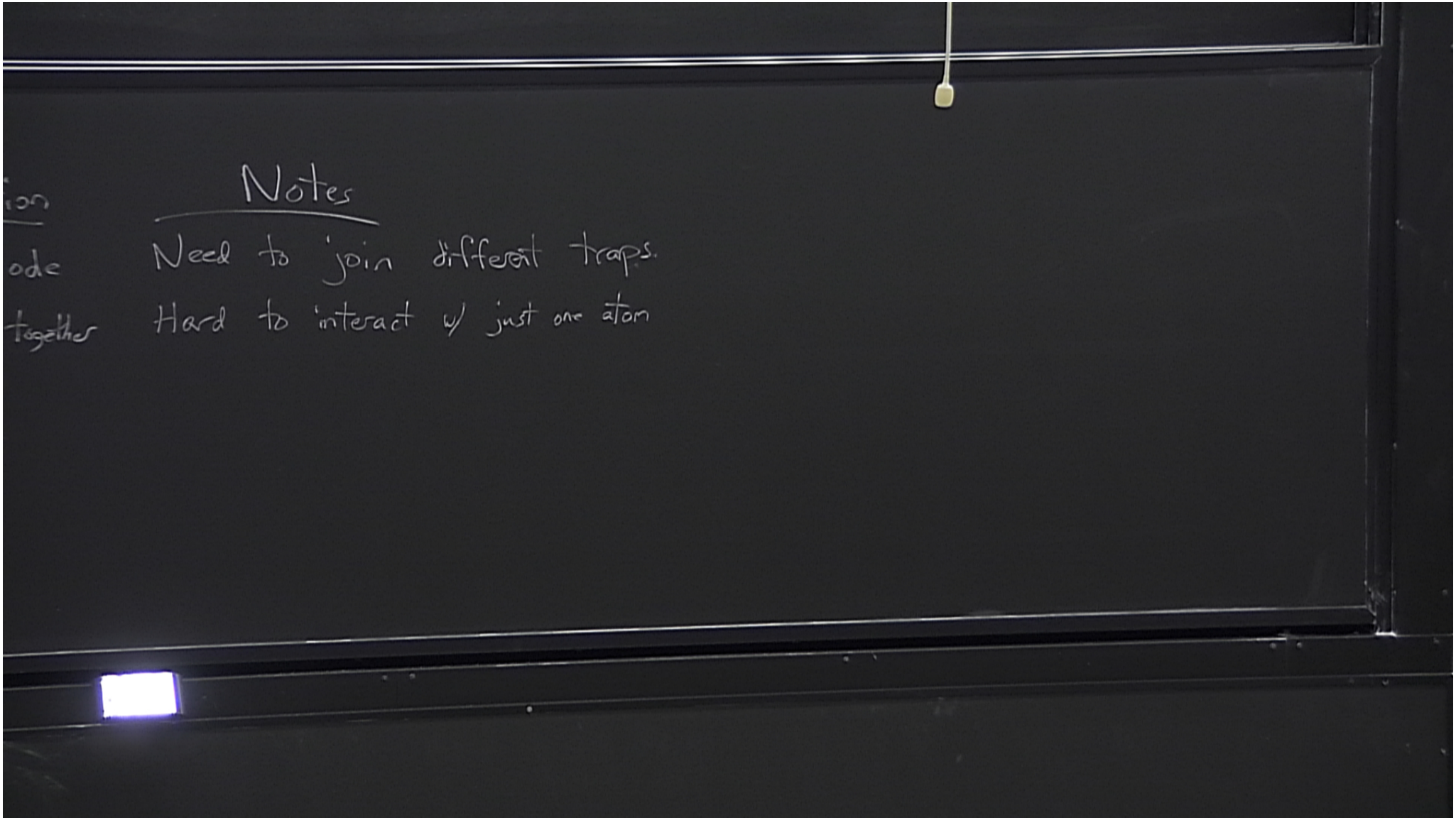
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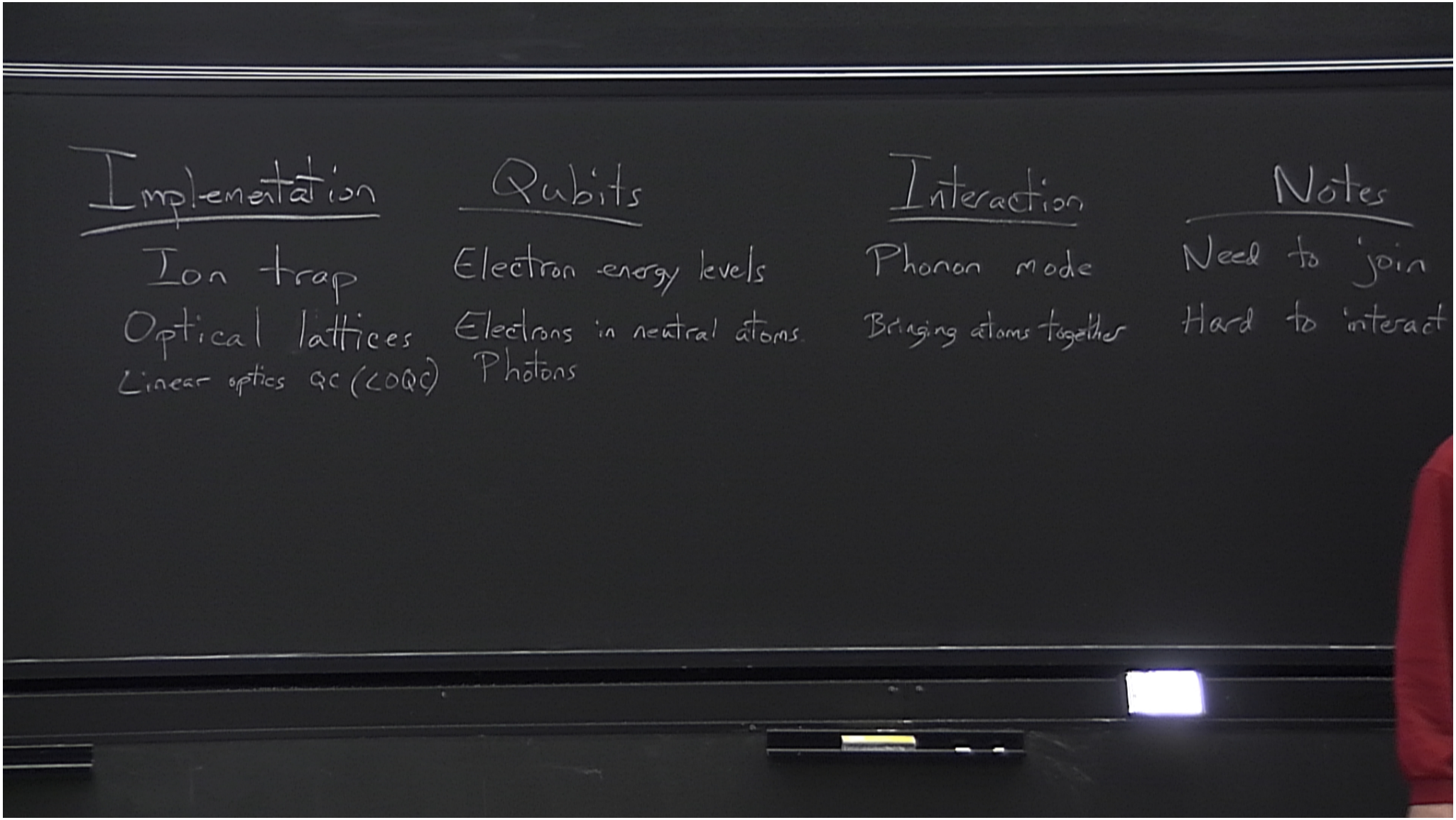

Implementation
Qubits
Ion trap
Electron energy levels

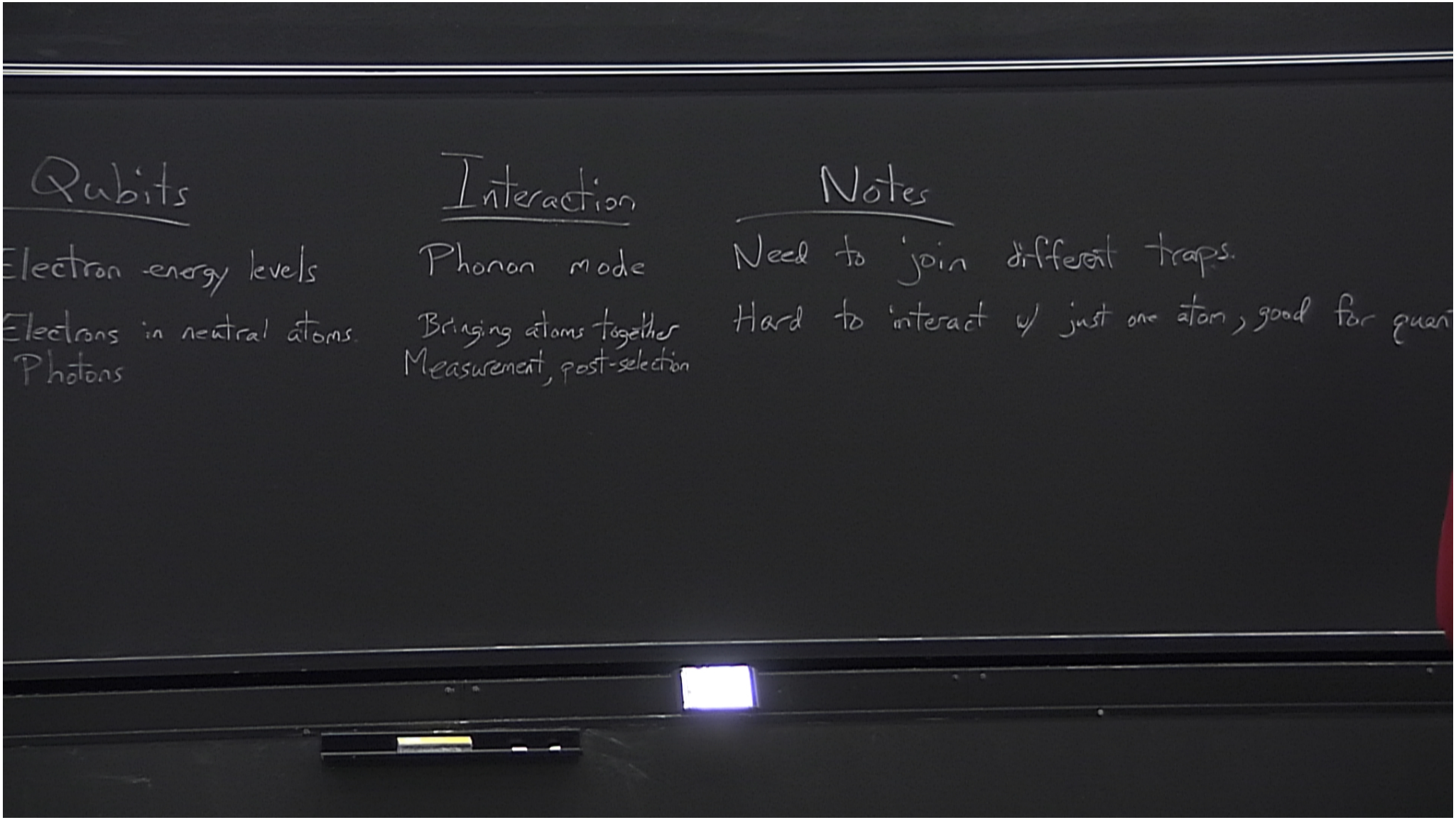

Implementation
Qubits
Interaction
Ion trap
Electron energy levels
Phonon mode

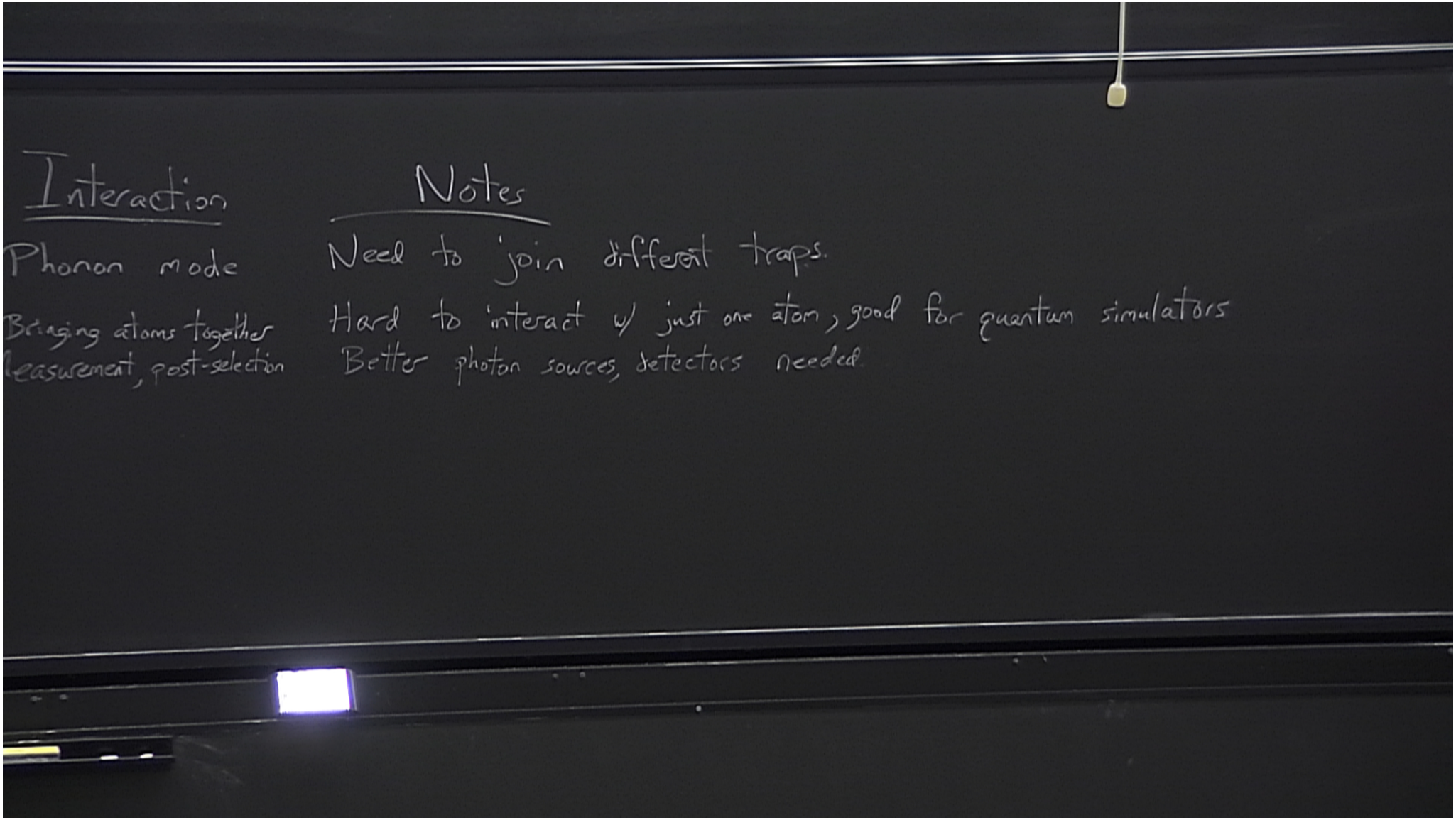

its
Interaction
Notes
energy levels
Phonon mode
Need to join different traps.

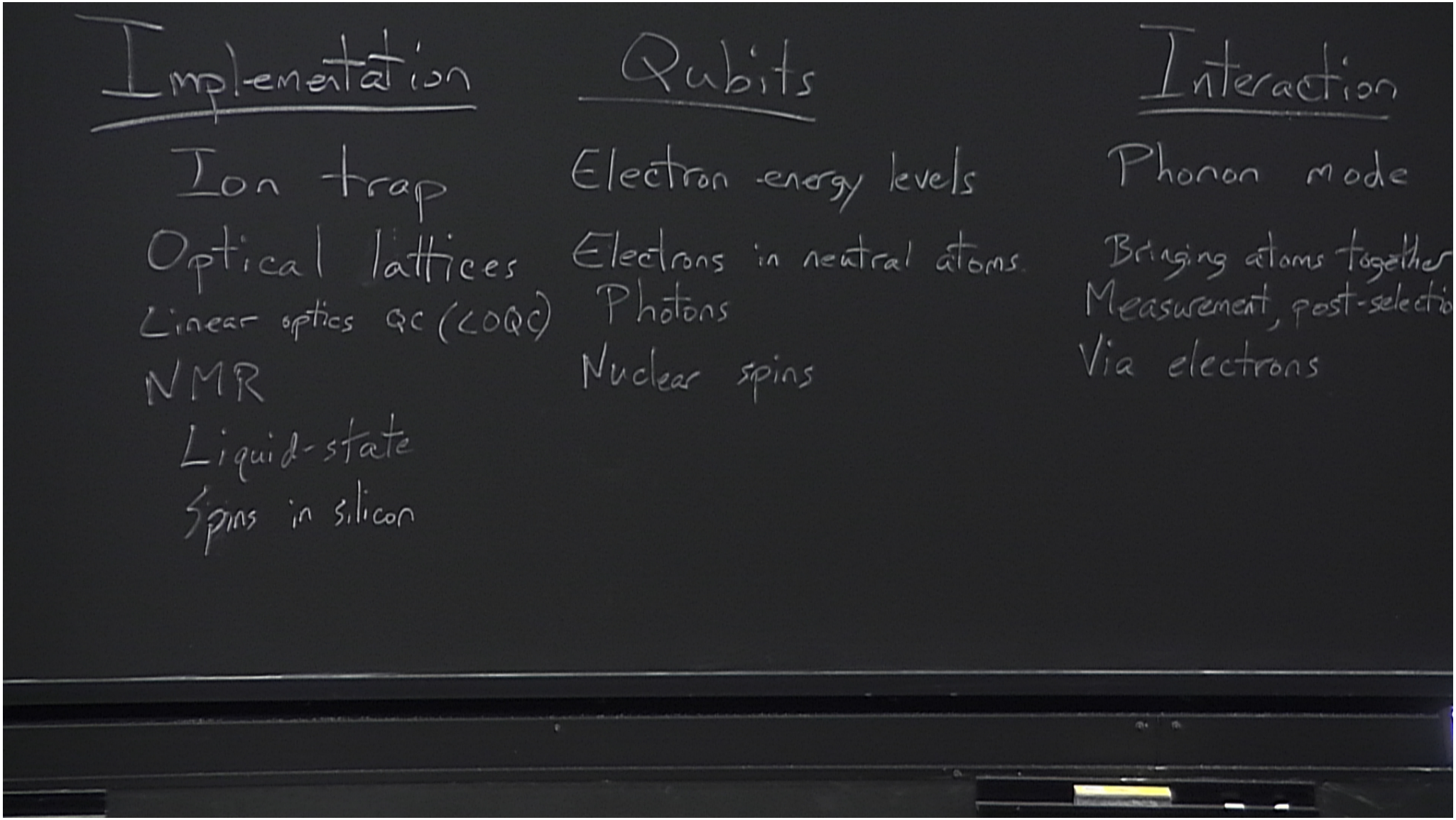

Implementation
Qubits
Interaction
Notes
Ion trap
Electron energy levels
Phonon mode
Optical lattices
Electrons in neutral atoms
Bringing atoms to

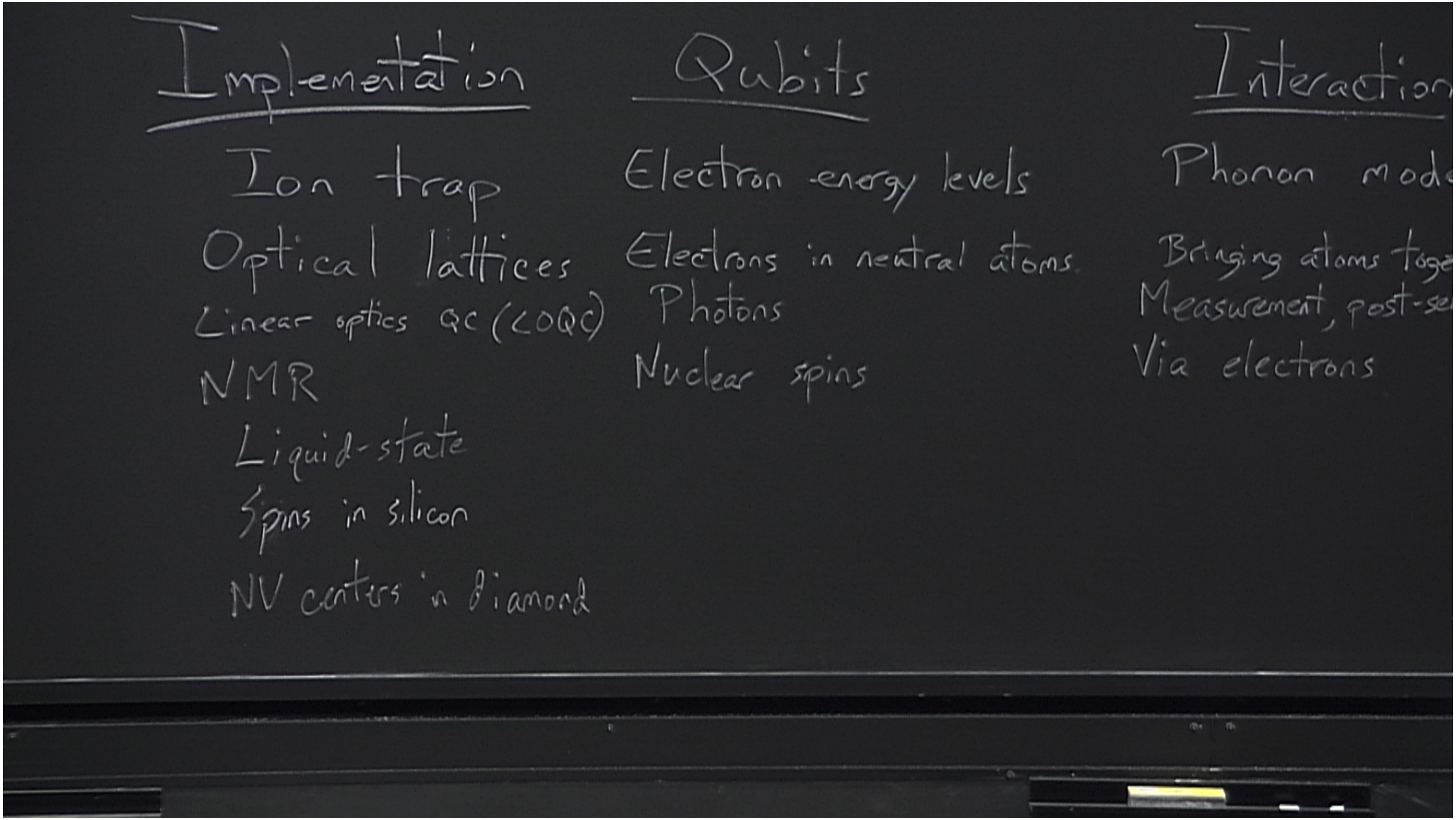

ion
ode
together
Notes
Need to join different traps.
Hard to interact w/ just one atom

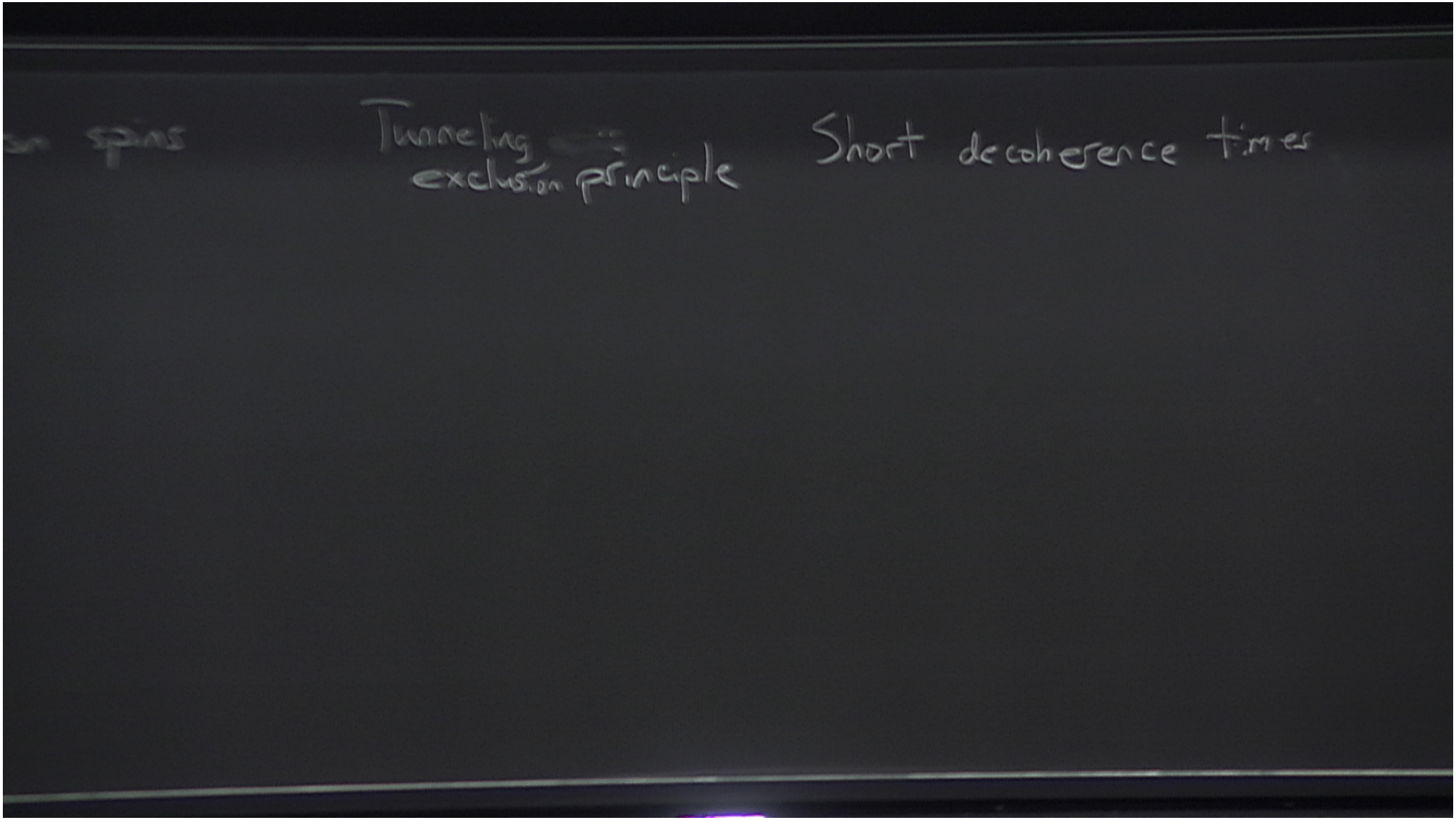

Implementation
Qubits
Interaction
Notes
Ion trap
Electron energy levels
Phonon mode
Need to join
Optical lattices
Electrons in neutral atoms
Bringing atoms together
Hard to interact
Linear optics QC (LOQC)
Photons

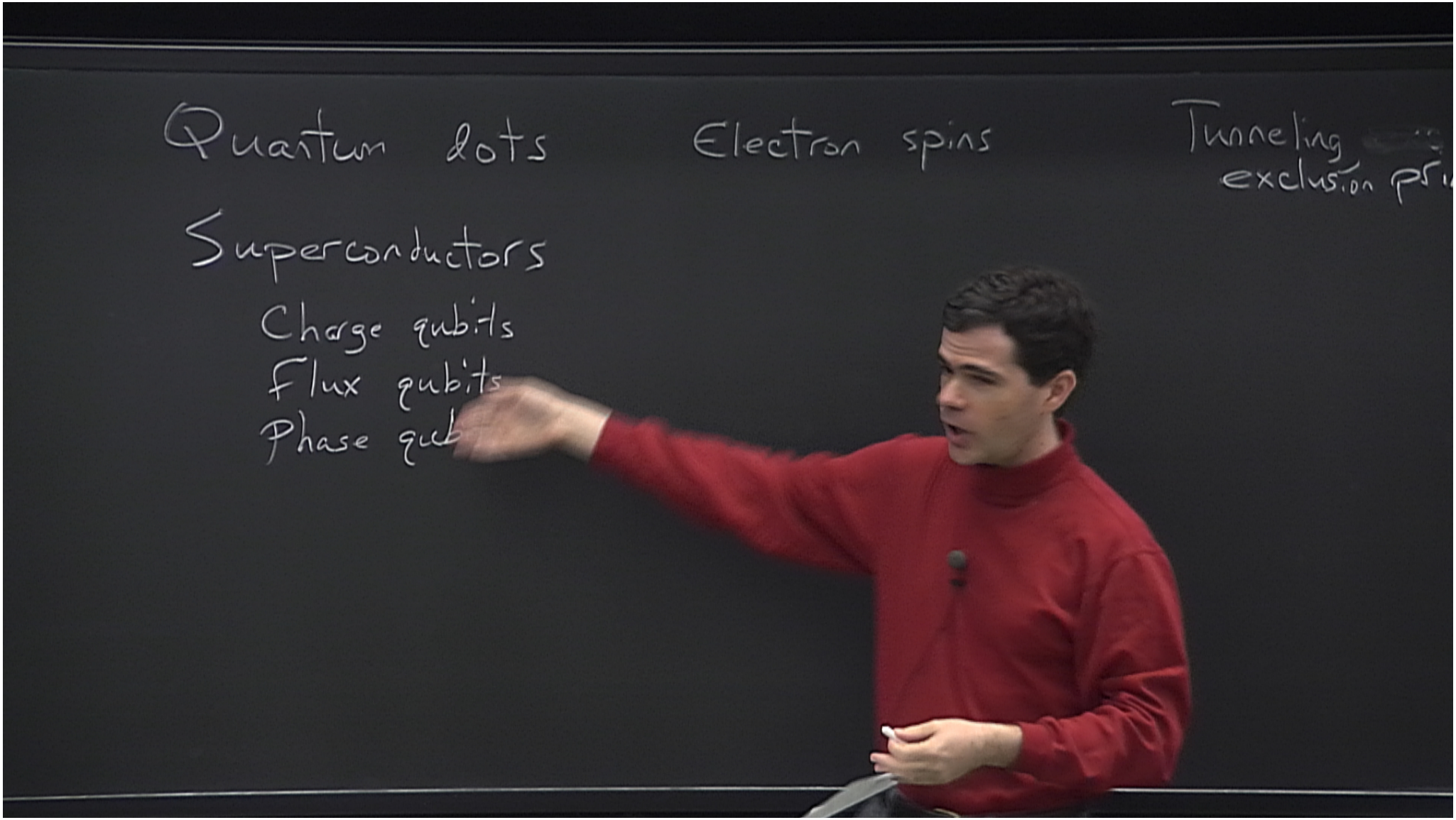

Qubits
Electron energy levels
Electrons in neutral atoms
Photons
Interaction
Phonon mode
Bringing atoms together
Measurement, post-selection
Notes
Need to join different traps.
Hard to interact w/ just one atom, good for quan

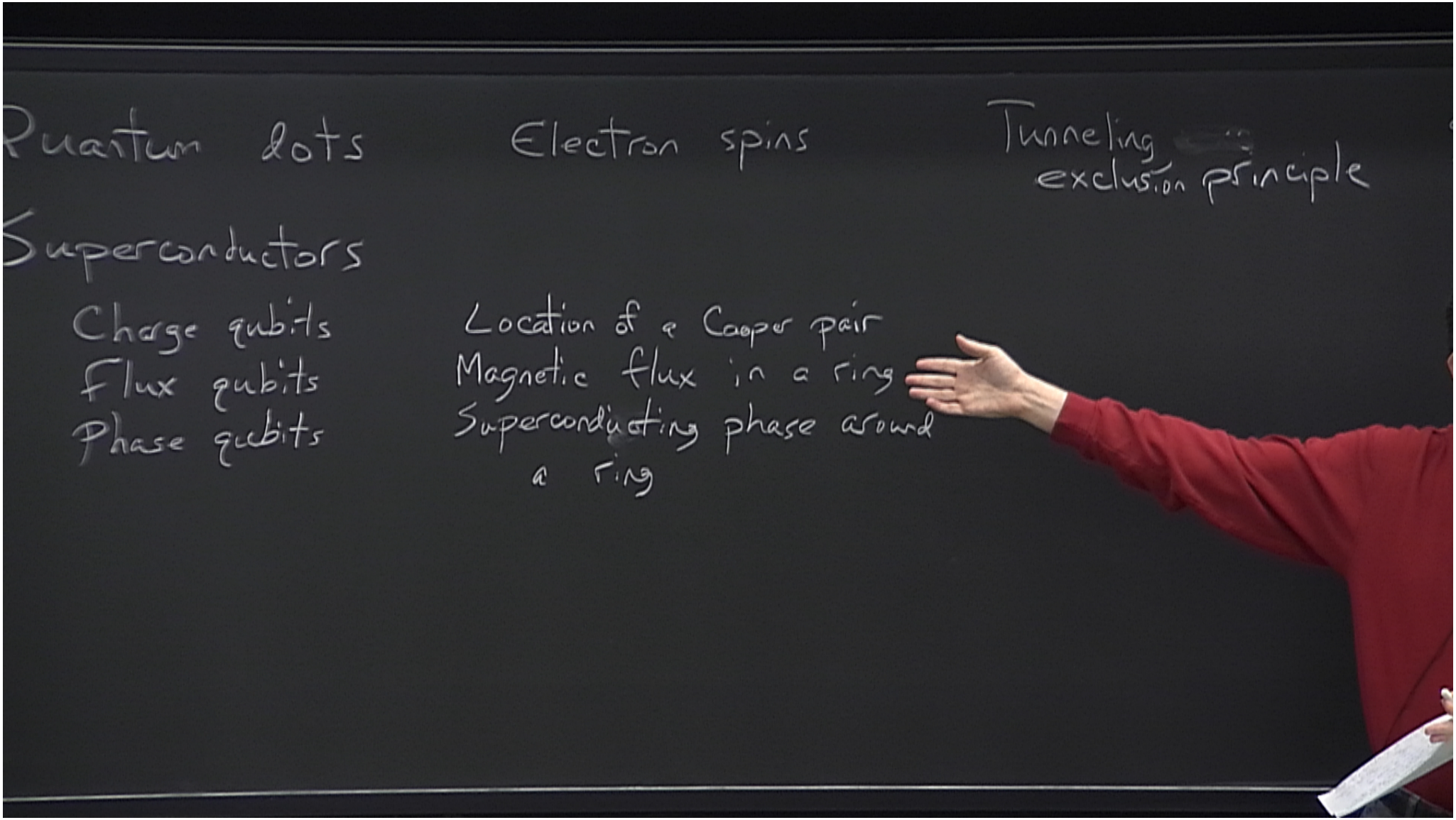

Interaction
Notes
Phonon mode
Need to join different traps.
Bringing atoms together
Hard to interact w/ just one atom, good for quantum simulators
Measurement, post-selection
Better photon sources, detectors needed


Implementation
Qubits
Interaction
Ion trap
Optical lattices
Linear optics QC (LOQC)
NMR
Liquid-state
Spins in silicon
Electron energy levels
Electrons in neutral atoms
Photons
Nuclear spins
Phonon mode
Bringing atoms together
Measurement, post-selectio
Via electrons


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spins
Tunneling
exclusion principle
Short decoherence times


Quantum dots
Electron spins
Tunneling
exclusion pri
Superconductors
Charge qubits
Flux qubits
Phase qub


Quantum dots
Electron spins
Tunneling
exclusion principle
Superconductors
Charge qubits
Flux qubits
Phase qubits
Location of a Cooper pair
Magnetic flux in a ring
Superconducting phase around a ring

Quantum dots

Superconductors

Charge qubits — Location of a Cooper pair

Flux qubits — Magnetic flux in a ring

Phase qubits — Superconducting phase around a ring

Electron spins

Tunneling

exclusion principle



Tunneling

exclusion principle

Short decoherence times

Non-linear inductors

Poor decoherence time

Tunneling
exclusion principle

Short decoherence times

Non-linear inductors

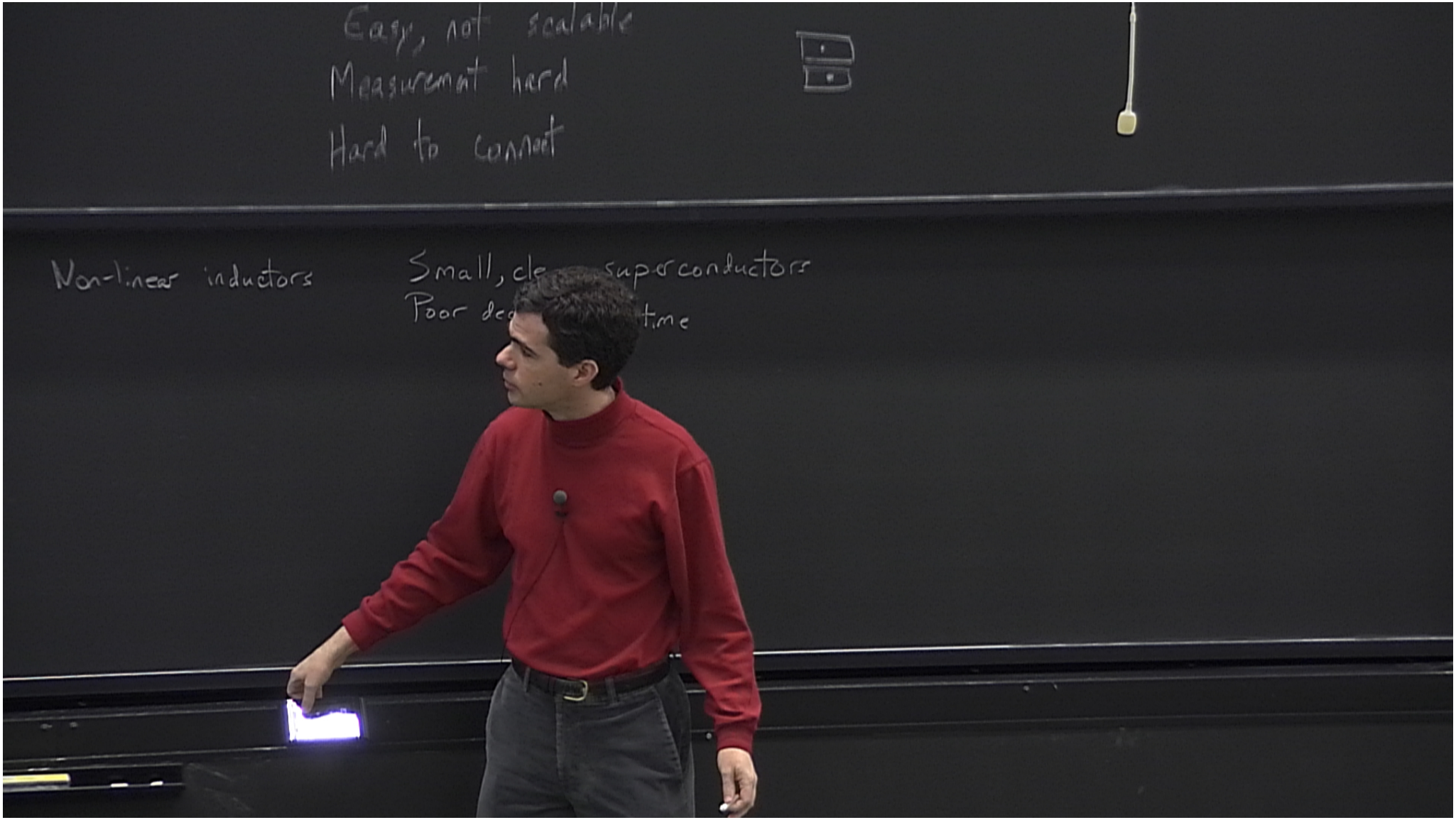
Small, clean superconductors
Poor decoherence time

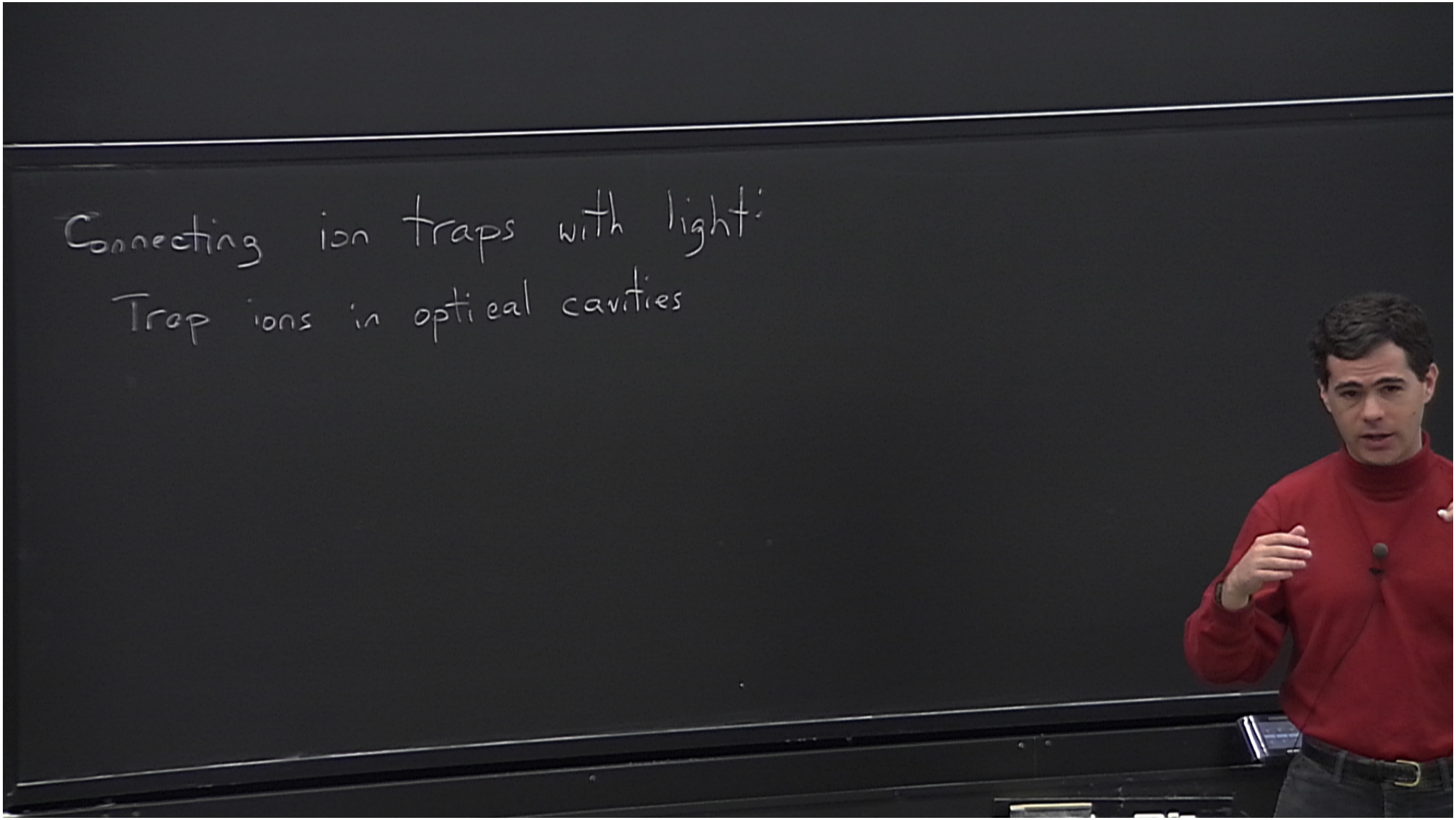
Tunneling
exclusion principle

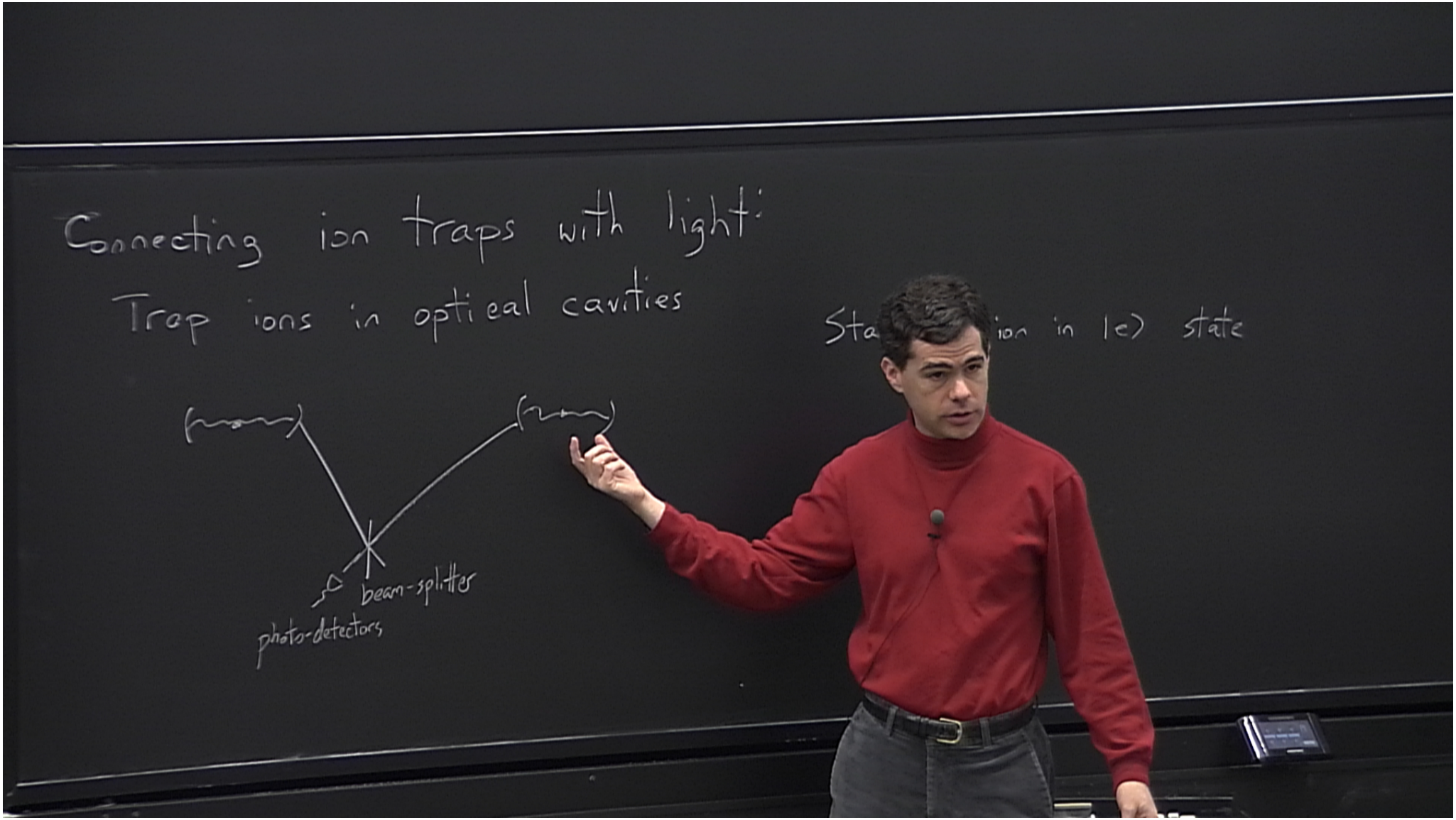
Short decoherence times

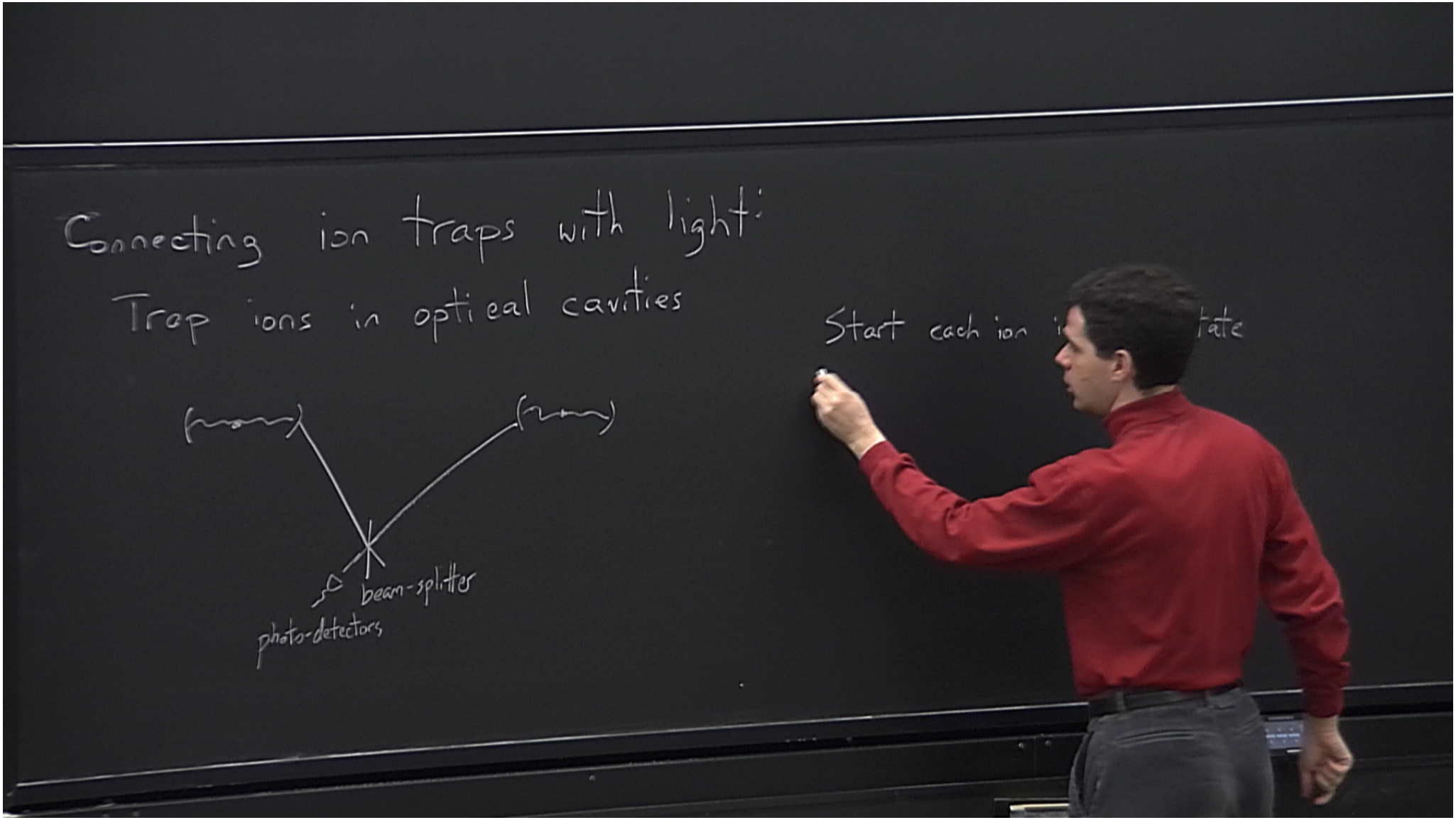
Non-linear inductors

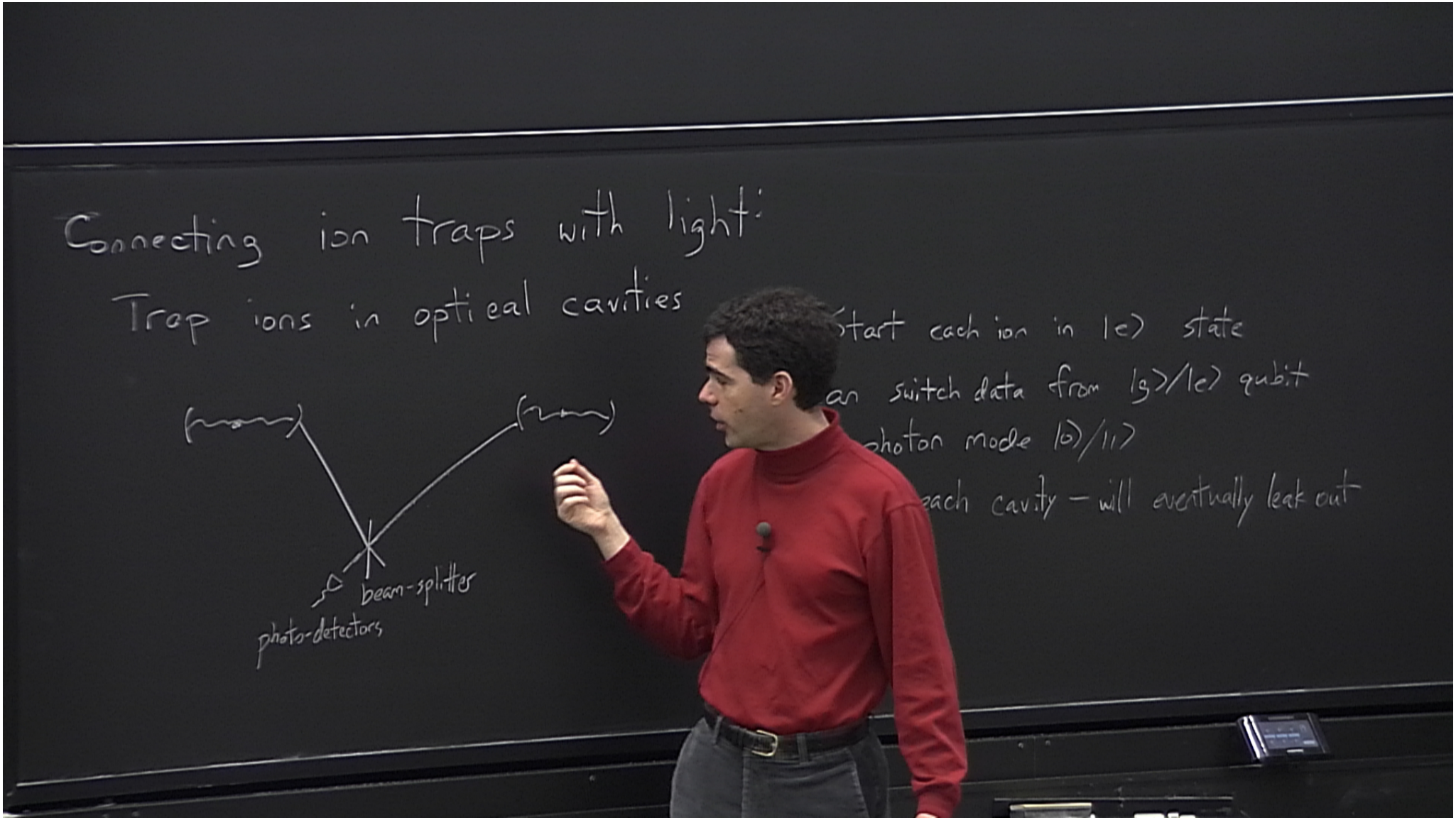
Small, clean superconductors
Poor decoherence time


Easy, not scalable
Measurement hard
Hard to connect
Non-linear inductors
Small, cle superconductors
Poor de time


Connecting ion traps with light:
Trap ions in optical cavities

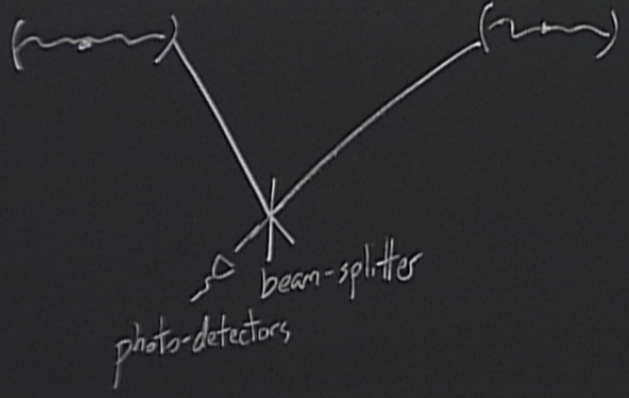

Connecting ion traps with light:
Trap ions in optical cavities
Sta ion in |e⟩ state
beam-splitter
photo-detectors


Connecting ion traps with light:
Trap ions in optical cavities
beam-splitter
photo-detectors


Connecting ion traps with light:
Trap ions in optical cavities
start each ion in |e⟩ state
switch data from |g⟩/|e⟩ qubit
photon mode |0⟩/|1⟩
each cavity – will eventually leak out
beam-splitter
photo-detectors

Connecting ion traps with light:

Trap ions in optical cavities



Start each ion in $|e\rangle$ state

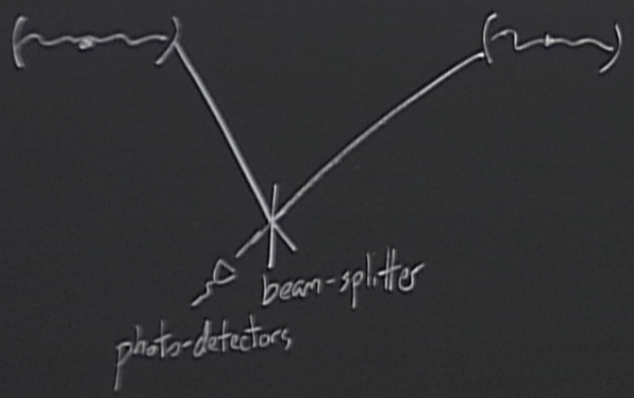
Can switch data [illegible] $|g\rangle/|e\rangle$ qubit to photon mode $|0\rangle/|1\rangle$

1 photon in each cavity – will eventually

Detection of photon does not tell us which cavity lost the photon

Connecting ion traps with light:

Trap ions in optical cavities



Start each ion in $|e\rangle$ state

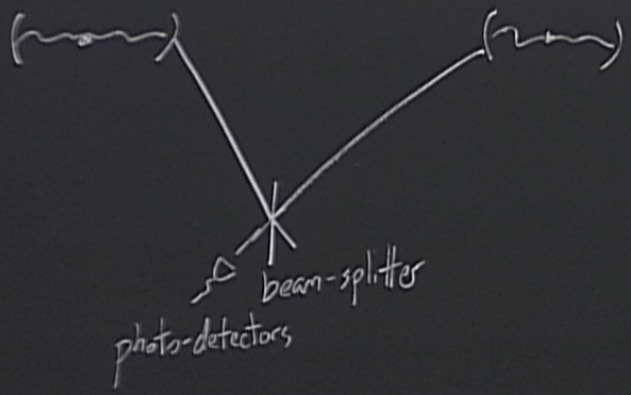
Can switch data from $|g\rangle/|e\rangle$ qubit to photon mode $|0\rangle/|1\rangle$

1 photon in each cavity – will eventually leak out

Detection of photon does not tell us which cavity lost the photon $\Rightarrow$ state is $|0\rangle|1\rangle$

Connecting ion traps with light:

Trap ions in optical cavities



Start each ion in $|e\rangle$ state

Can switch data from $|g\rangle/|e\rangle$ qubit to photon mode $|0\rangle/|1\rangle$

1 photon in each cavity – will eventually leak out

Detection of photon does not tell us which cavity lost the photon $\Rightarrow$ state is $(|01\rangle + |10\rangle)$

Put entangled back in atoms

In NMR, have spin-spin coupling which is always on.

Doing 2-qubit gates is easy - just wait

But not doing 2-qubit gates is hard.

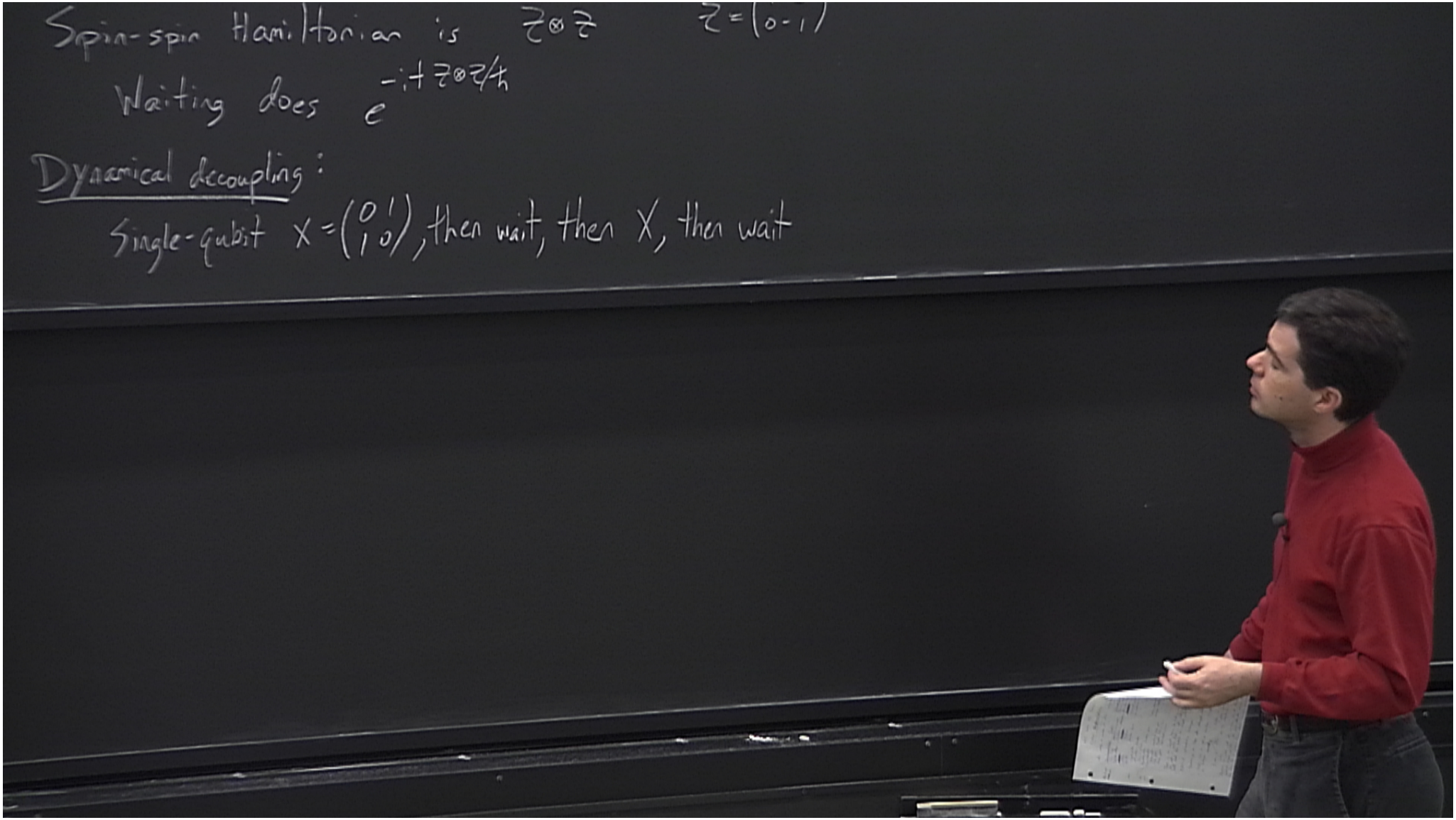


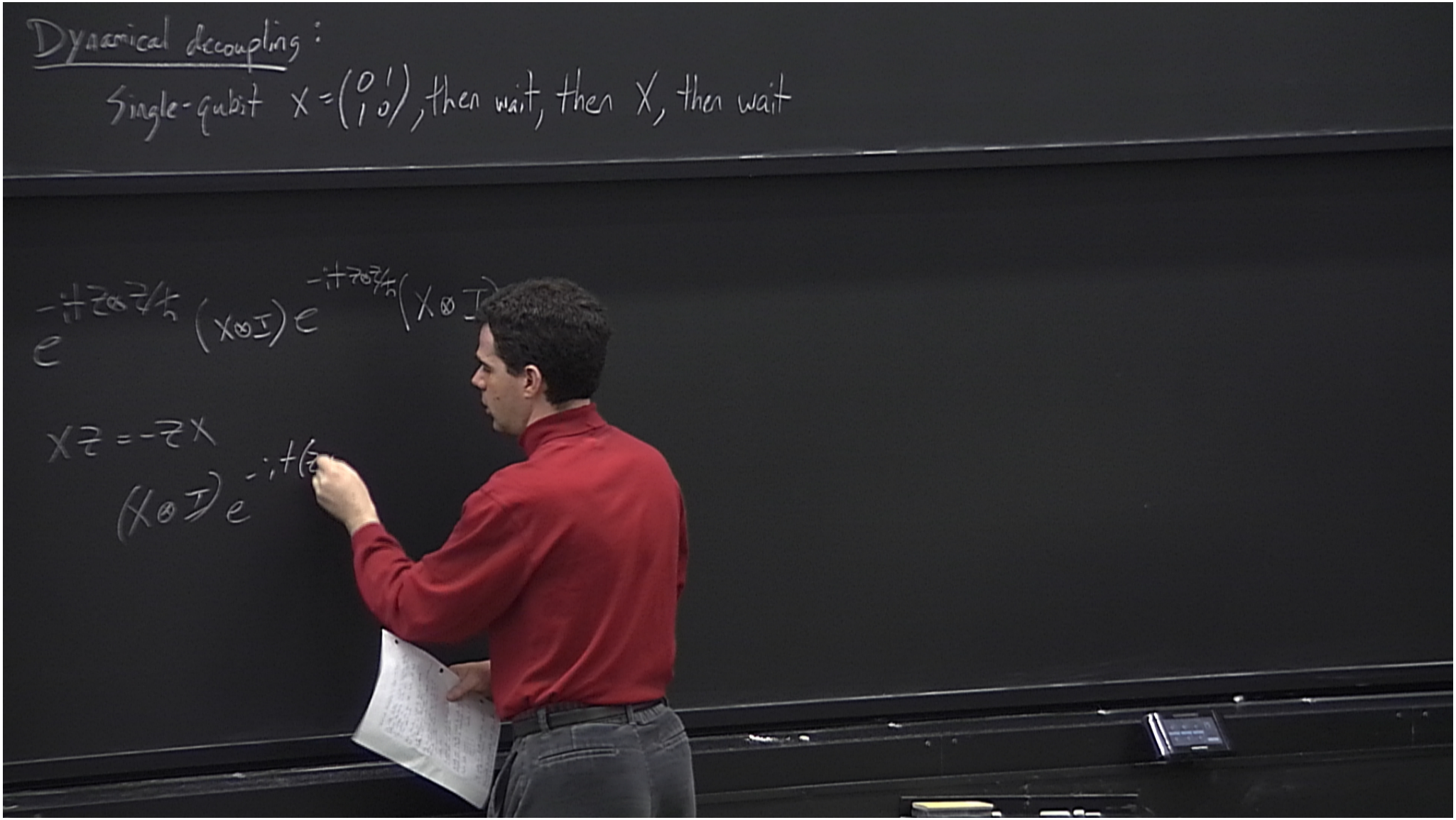
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Spin-spin Hamiltonian is $Z \otimes Z$ $\quad Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$


Spin-spin Hamiltonian is $Z \otimes Z$ $Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$
Waiting does $e^{-iHZ \otimes Z/\hbar}$
Dynamical decoupling:
Single-qubit $X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$, then wait, then X, then wait


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$XZ = -ZX$

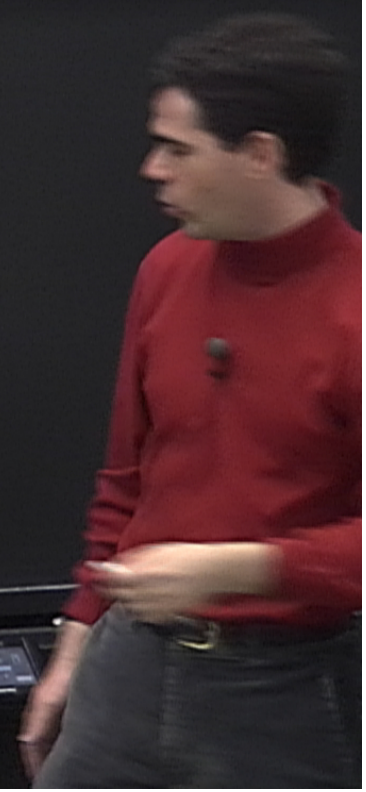
Dynamical decoupling:

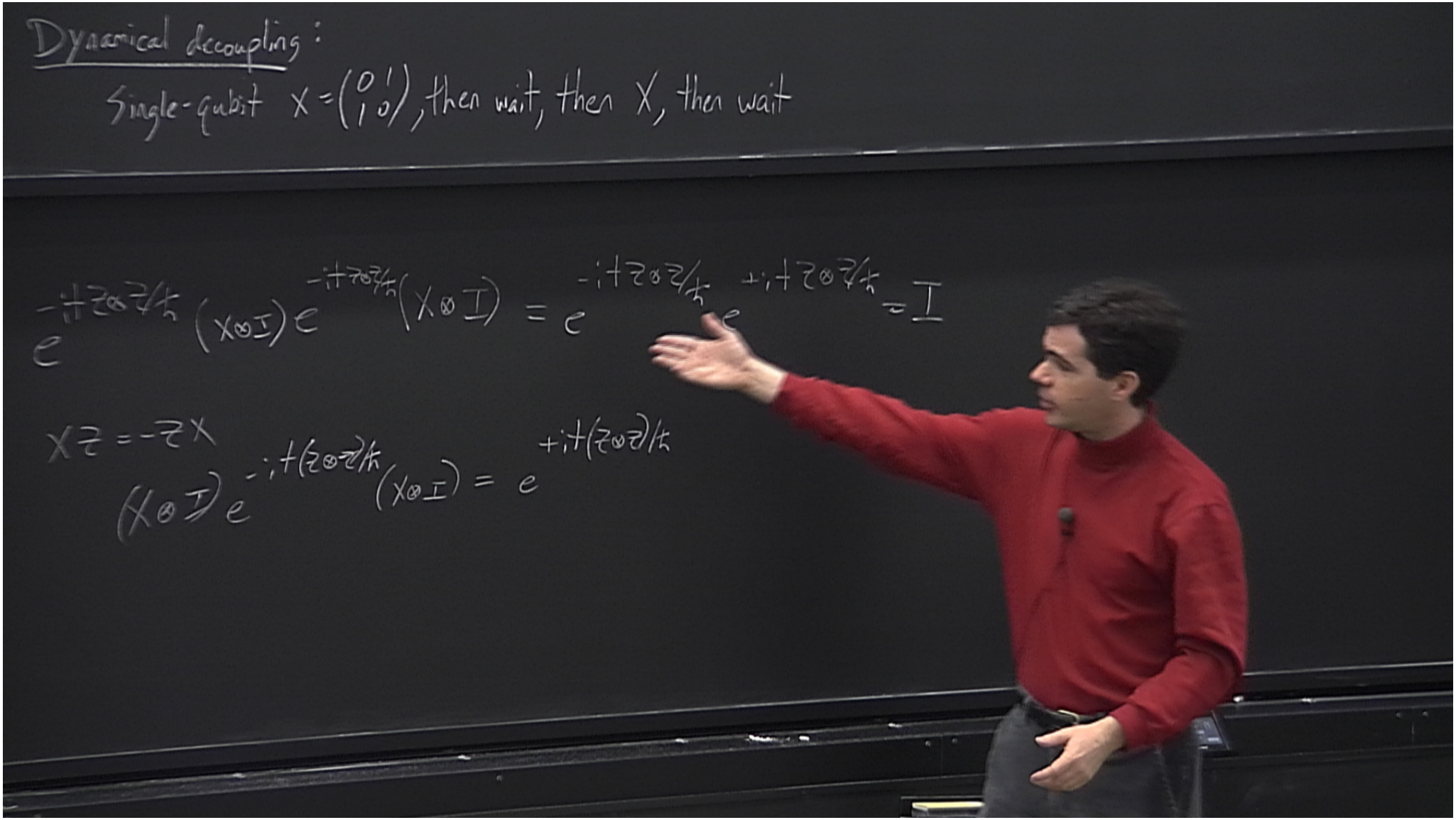
Single-qubit $X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$, then wait, then X, then wait

$$e^{-iH\tau/\hbar}(X\otimes I)\,e^{-iH\tau/\hbar}(X\otimes I) = e^{-iH\tau/\hbar}\,e^{+iH\tau/\hbar} = I$$

$$XZ = -ZX$$

$$(X\otimes I)\,e^{-iH(Z\otimes Z)\tau/\hbar}(X\otimes I) = e^{+iH(Z\otimes Z)\tau/\hbar}$$




Dynamical decoupling:
Single-qubit $X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$, then wait, then X, then wait
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$XZ = -ZX$
$(X\otimes I)e^{-iH(Z\otimes Z)\tau/\hbar}(X\otimes I) = e^{+iH(Z\otimes Z)\tau/\hbar}$

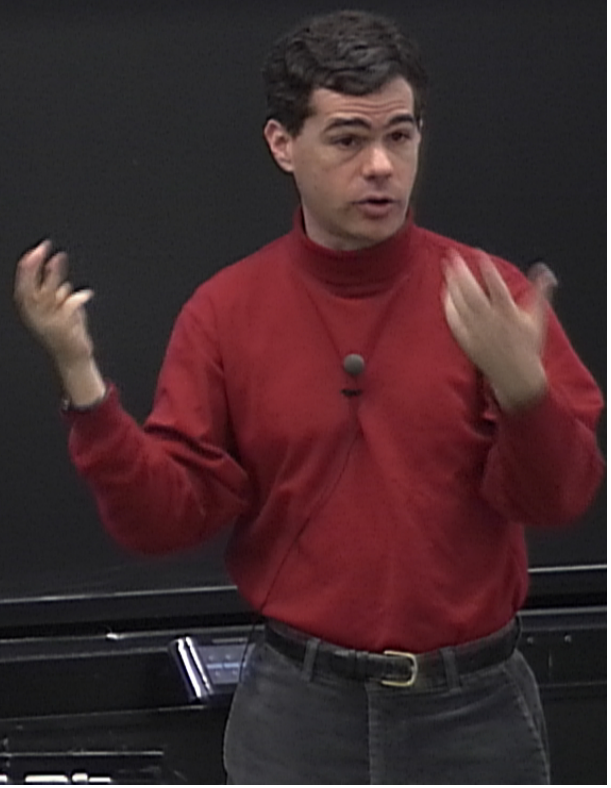
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Dynamical decoupling:

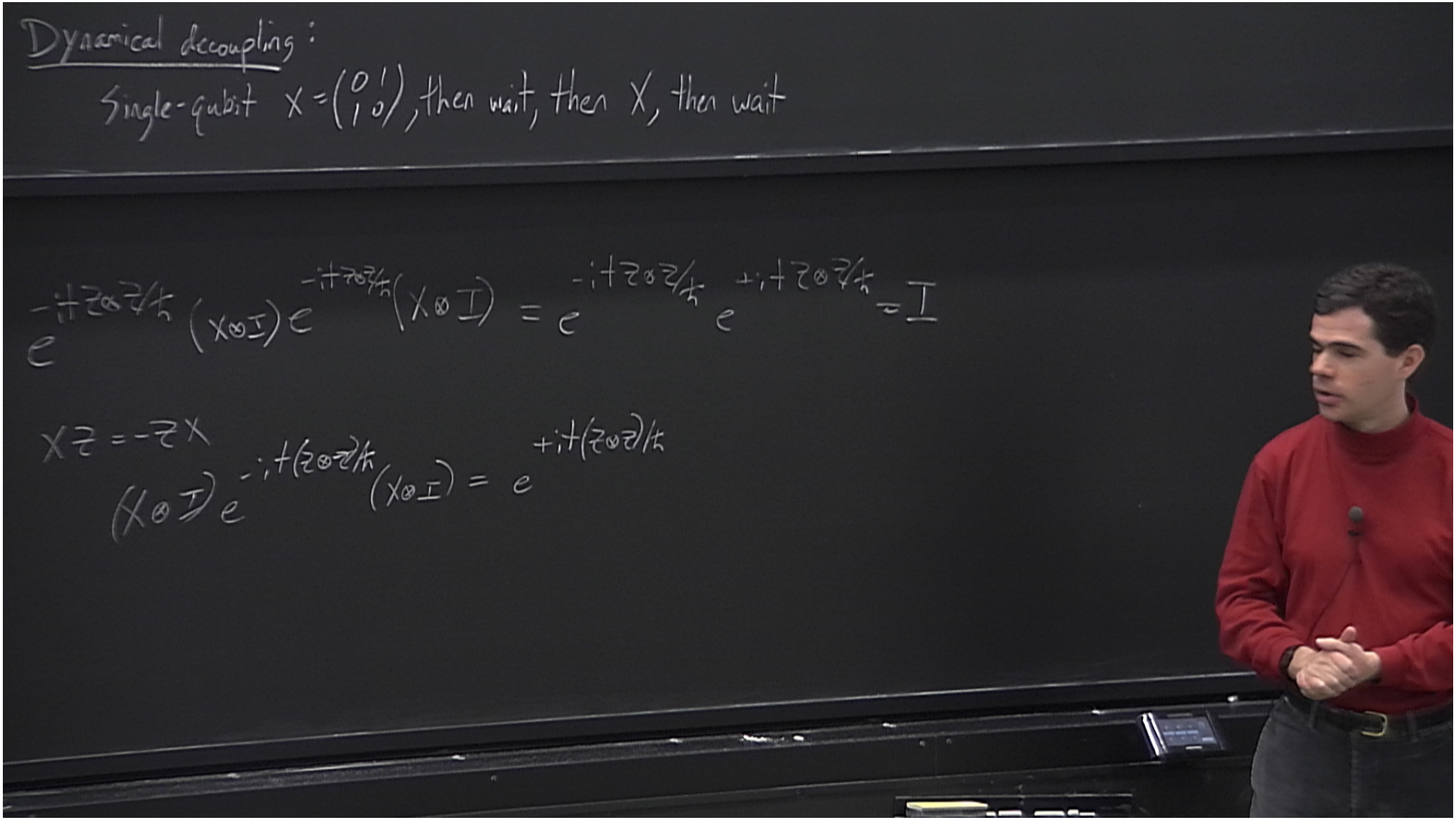
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$$e^{-iH\otimes Z/4} (X\otimes I) e^{-iH\otimes Z/4} (X\otimes I) = e^{-iH\otimes Z/4} e^{+iH\otimes Z/4} = I$$

$$XZ = -ZX$$

$$(X\otimes I) e^{-iH(Z\otimes Z)/4} (X\otimes I) = e^{+iH(Z\otimes Z)/4}$$




Dynamical decoupling:
Single-qubit $X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$, then wait, then X, then wait
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