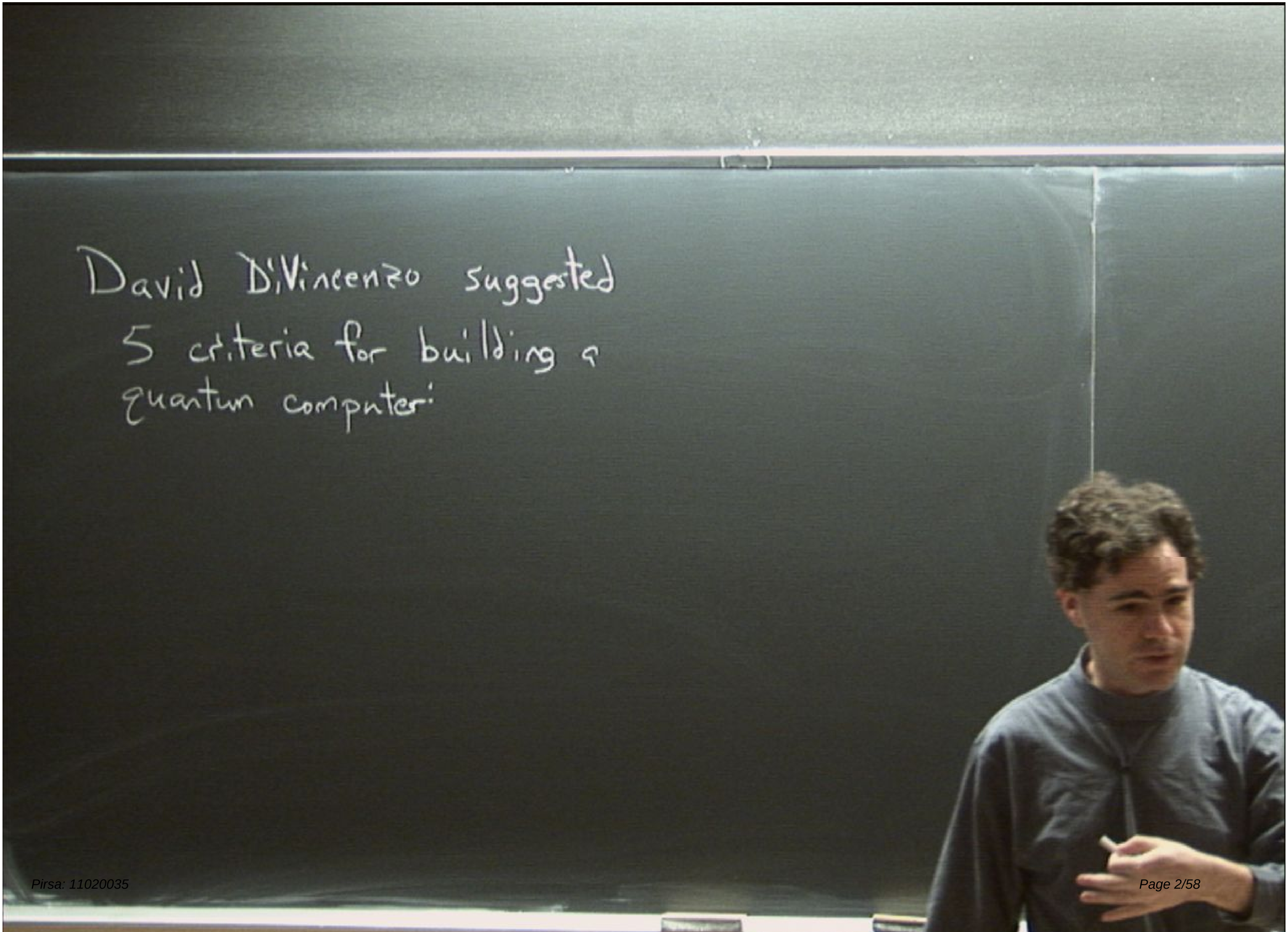
Title: Quantum Information Review - Lecture 3

Date: Feb 16, 2011 09:00 AM

URL: http://pirsa.org/11020035

Abstract:


David DiVincenzo suggested
5 criteria for building a
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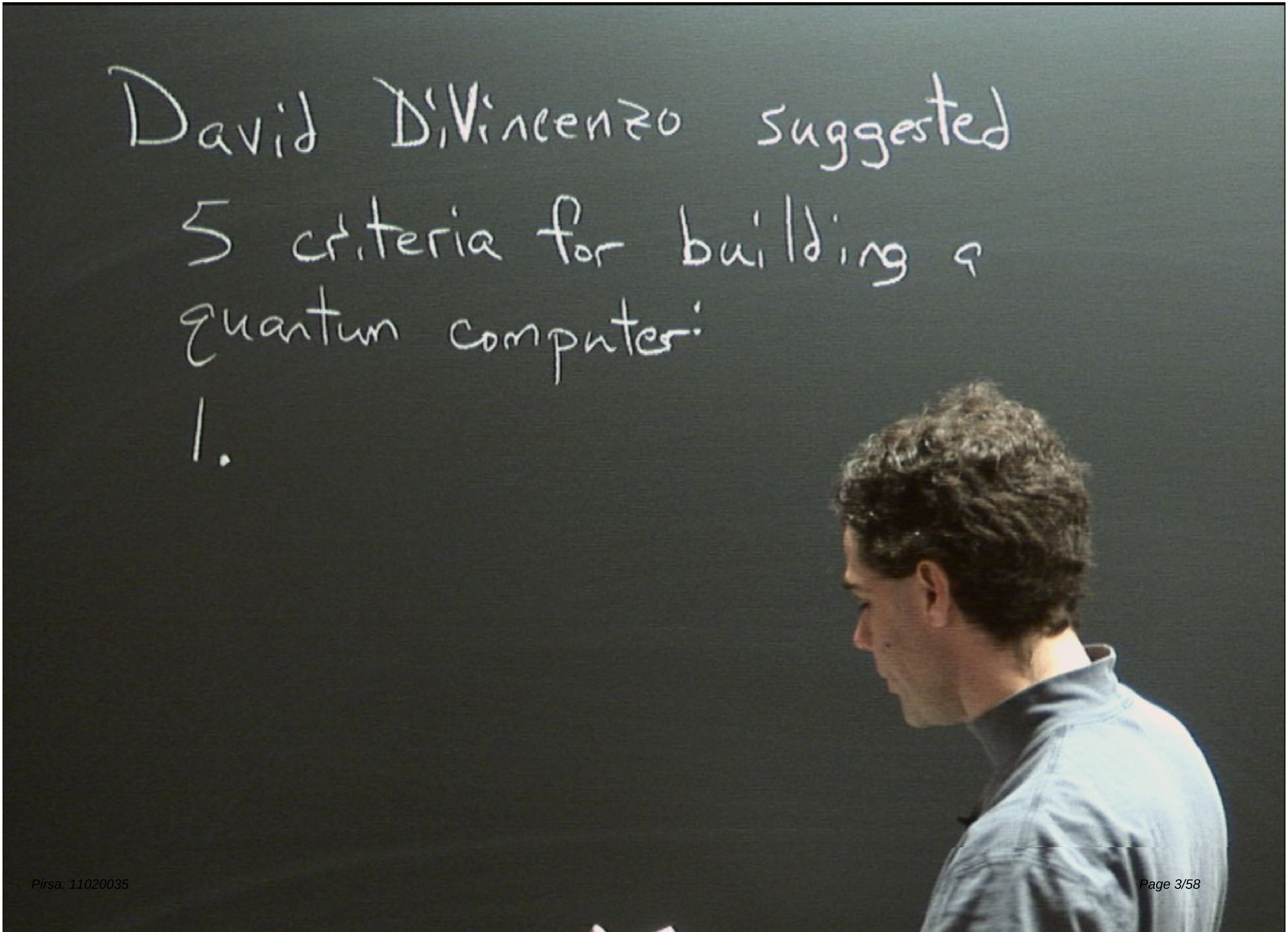
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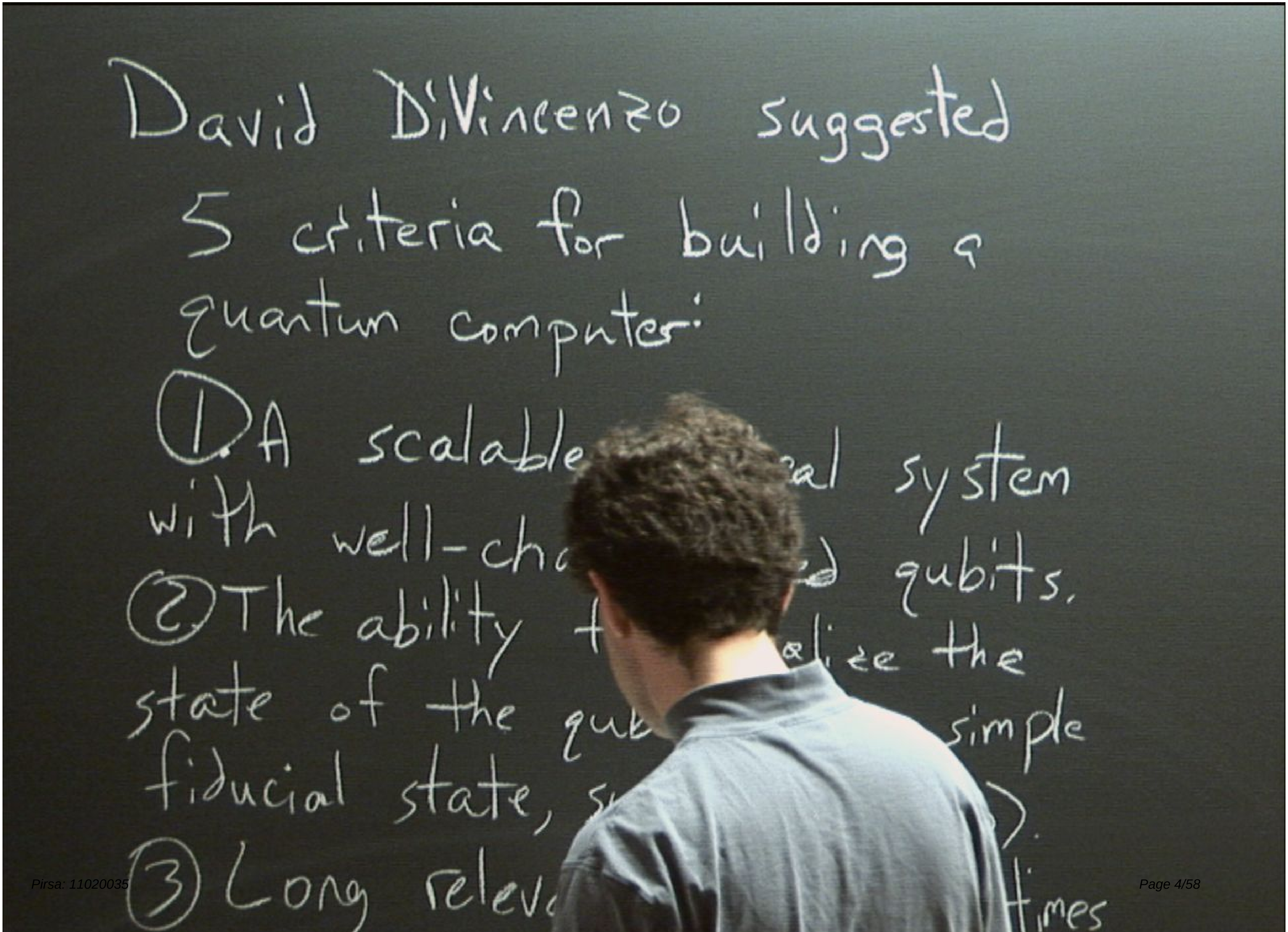
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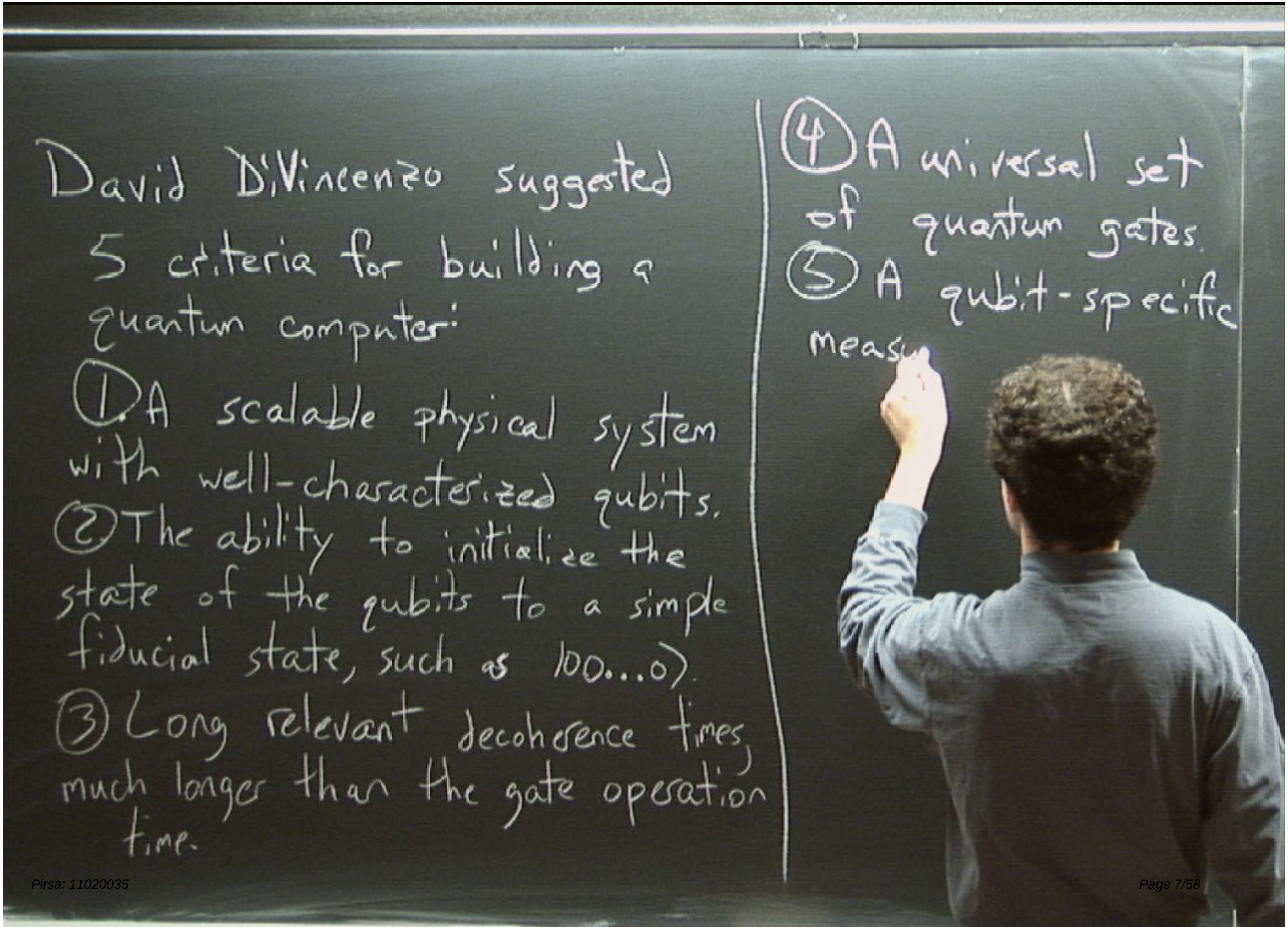
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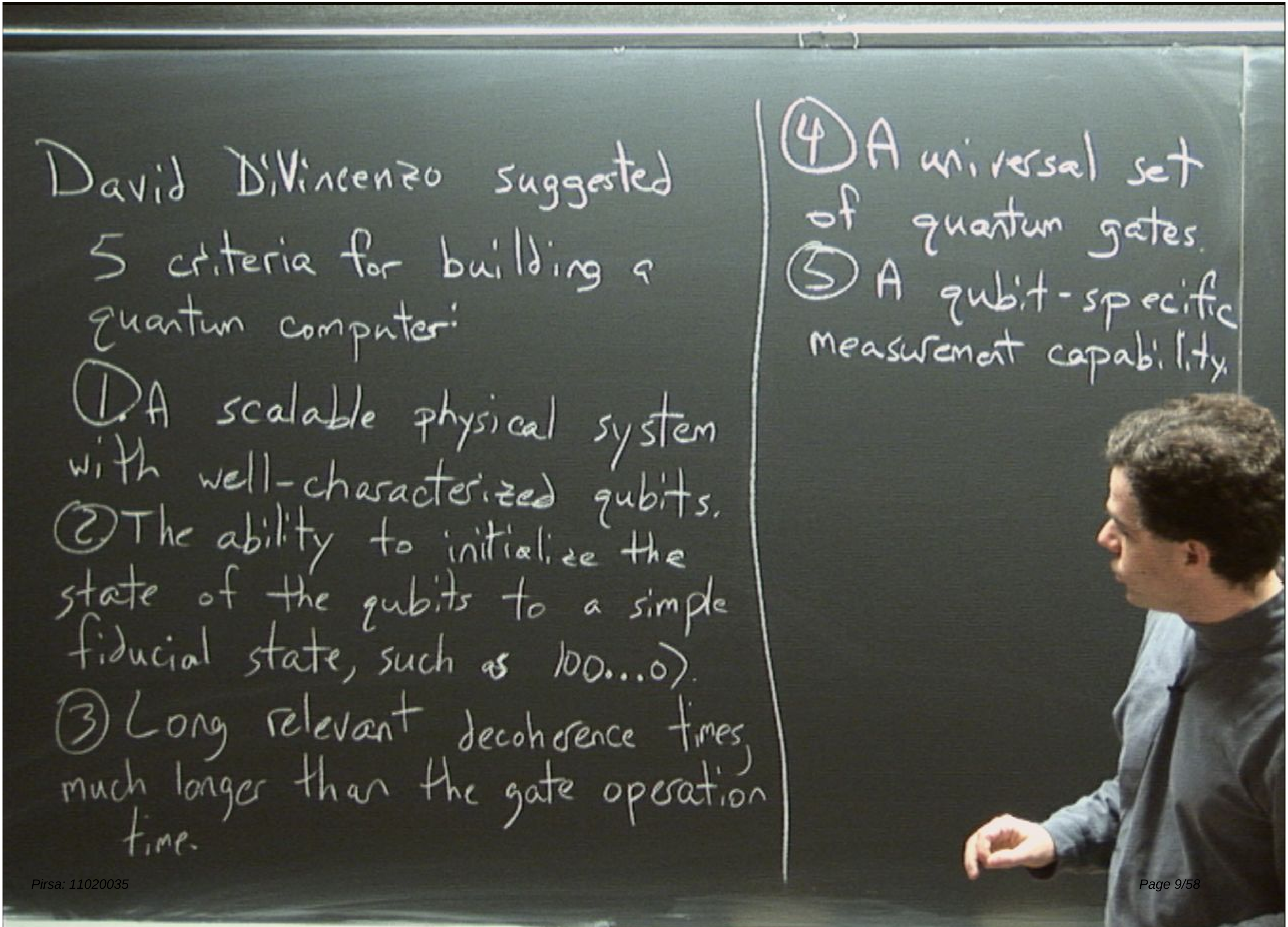
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(6) The ability to interconvert between stationary and flying qubits.

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Use group II atoms ionized once

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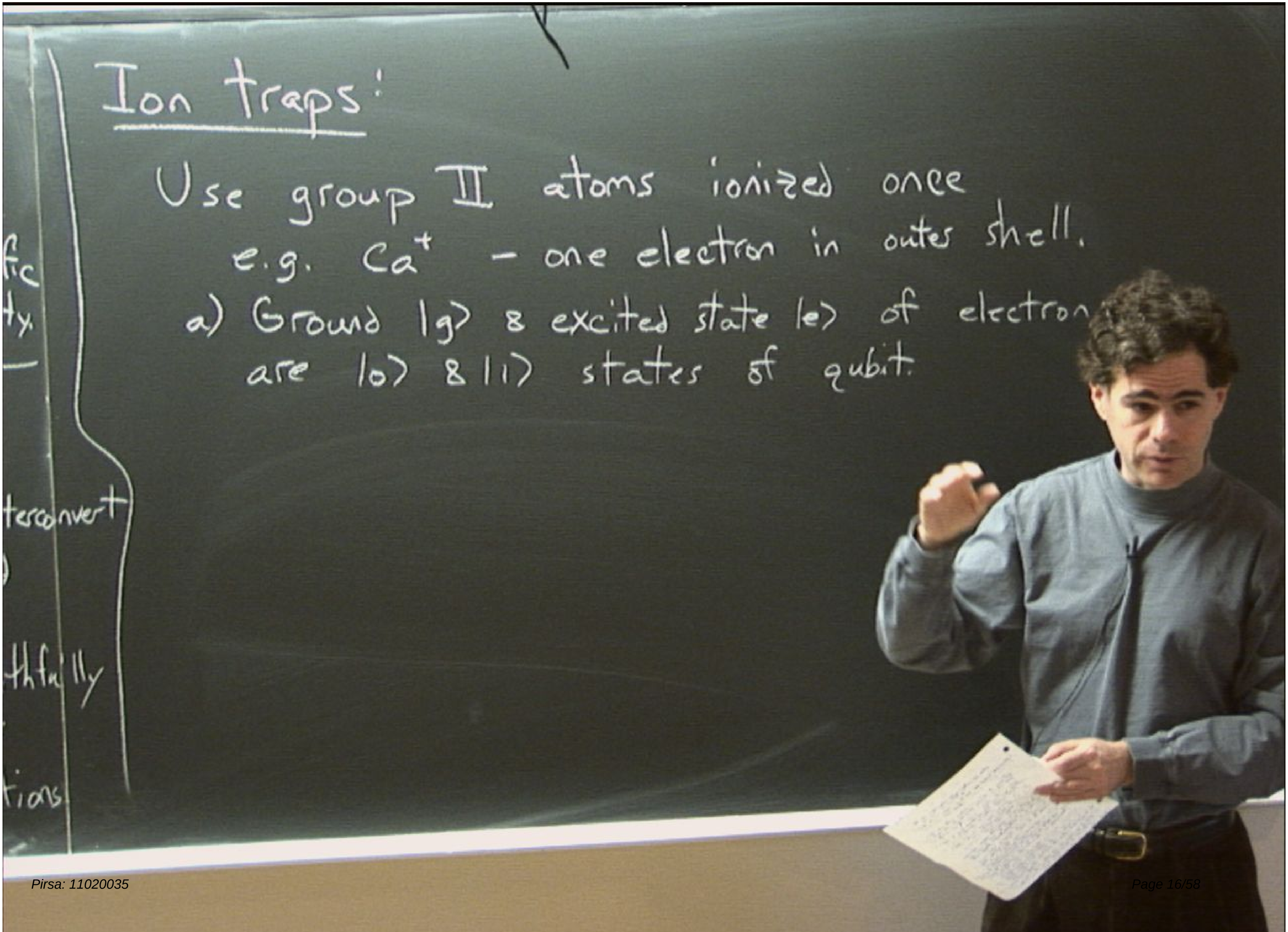
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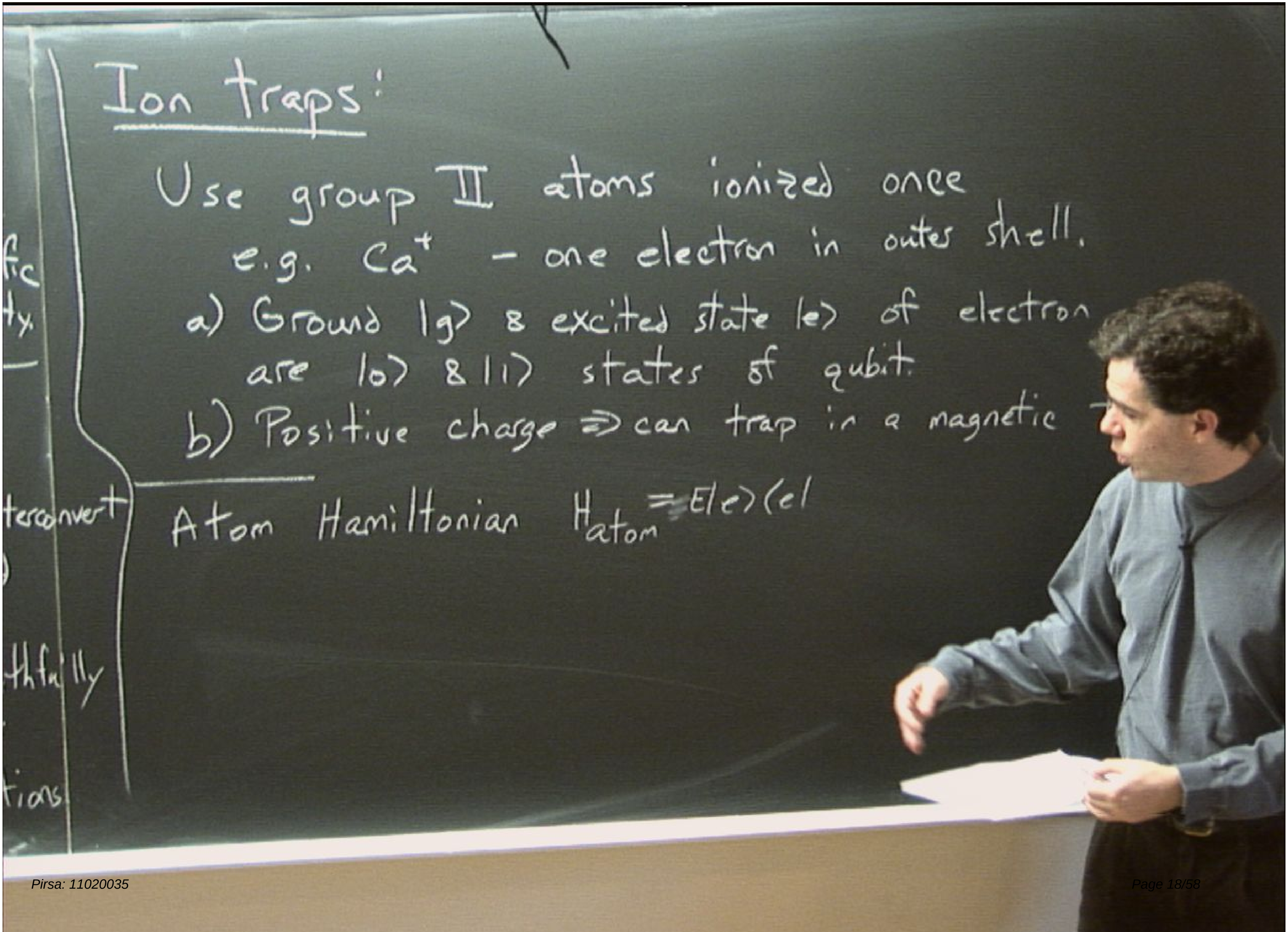
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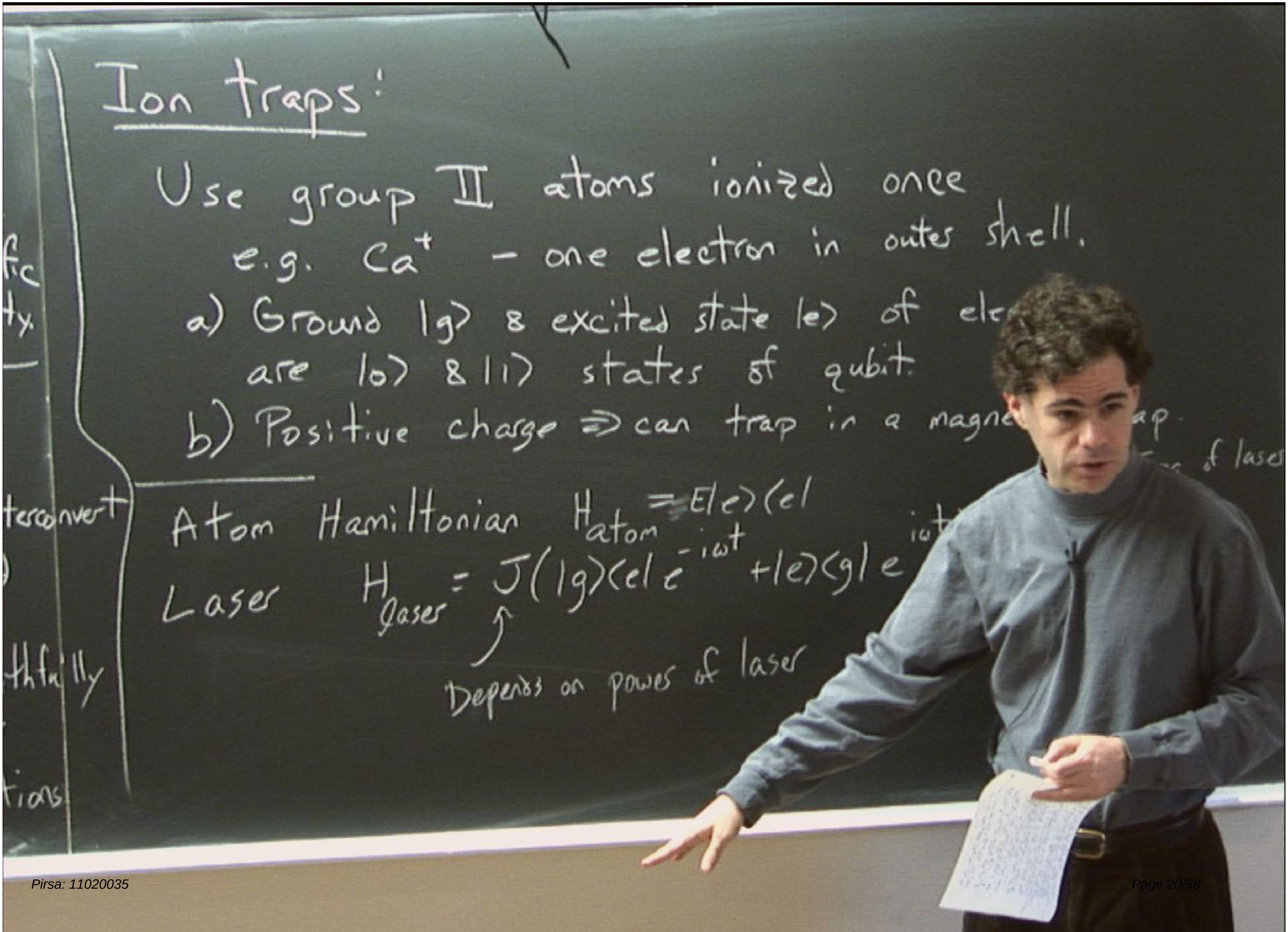
Laser $H_{laser} = J\left(|g\rangle\langle e| e^{-i\omega t} + |e\rangle\langle g| e^{i\omega t}\right)$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Freq. of laser

$\boxed{\hbar\omega = \epsilon}$

Depends on power of laser

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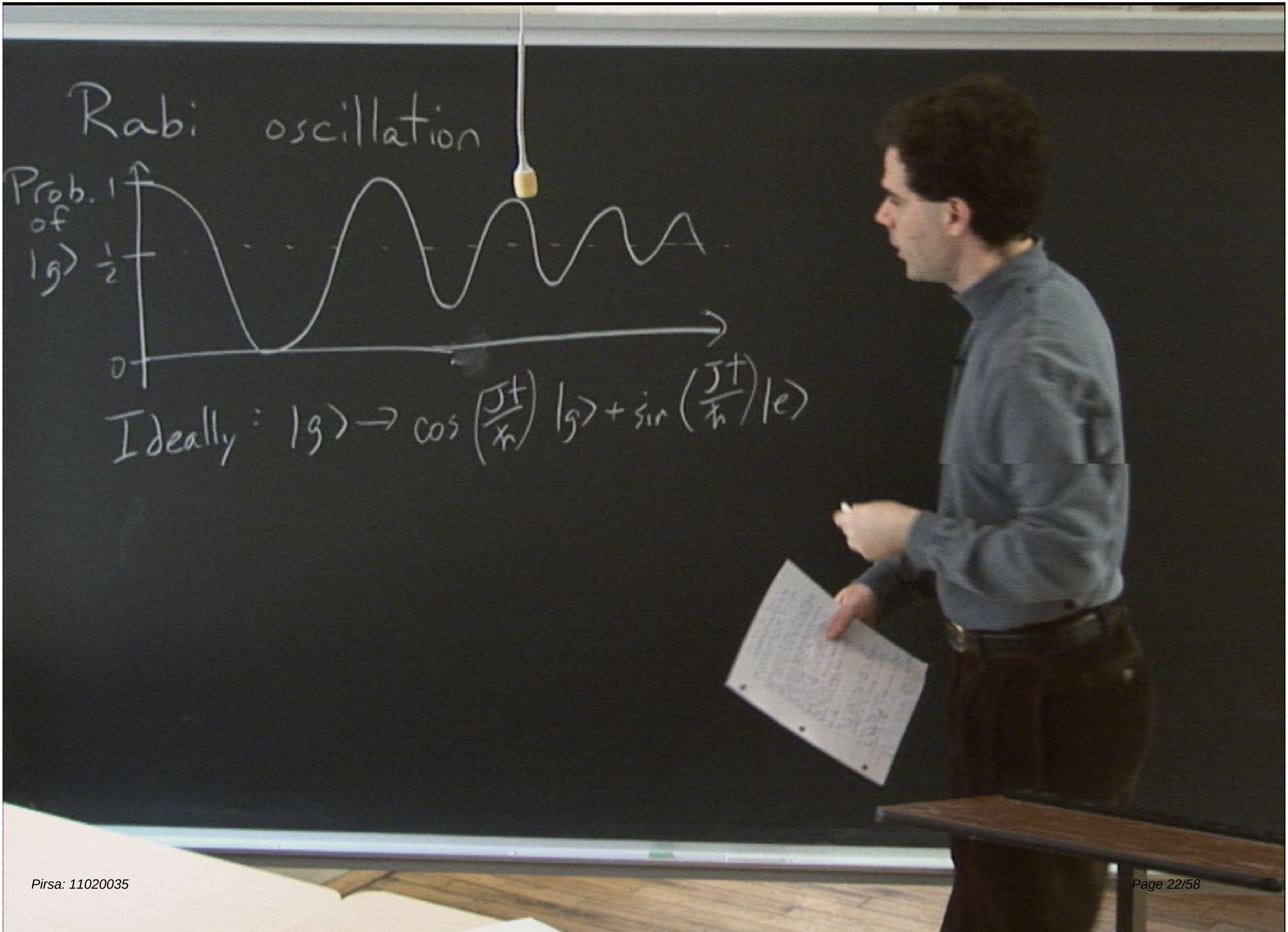
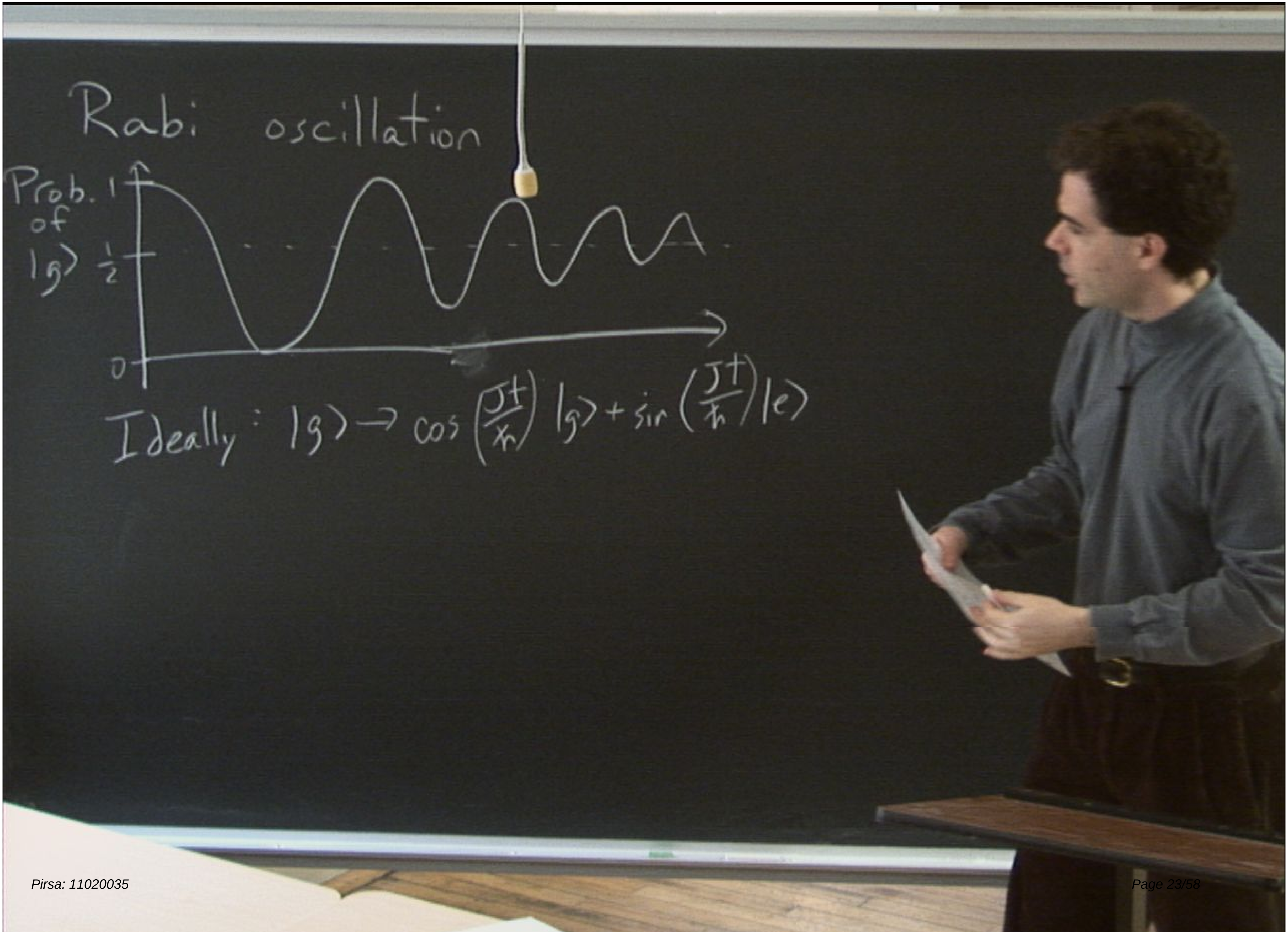

Rabi oscillation
Prob. of $|g\rangle$
1
$\frac{1}{2}$
0
Ideally: $|g\rangle \to \cos\left(\frac{Jt}{\hbar}\right)|g\rangle + \sin\left(\frac{Jt}{\hbar}\right)|e\rangle$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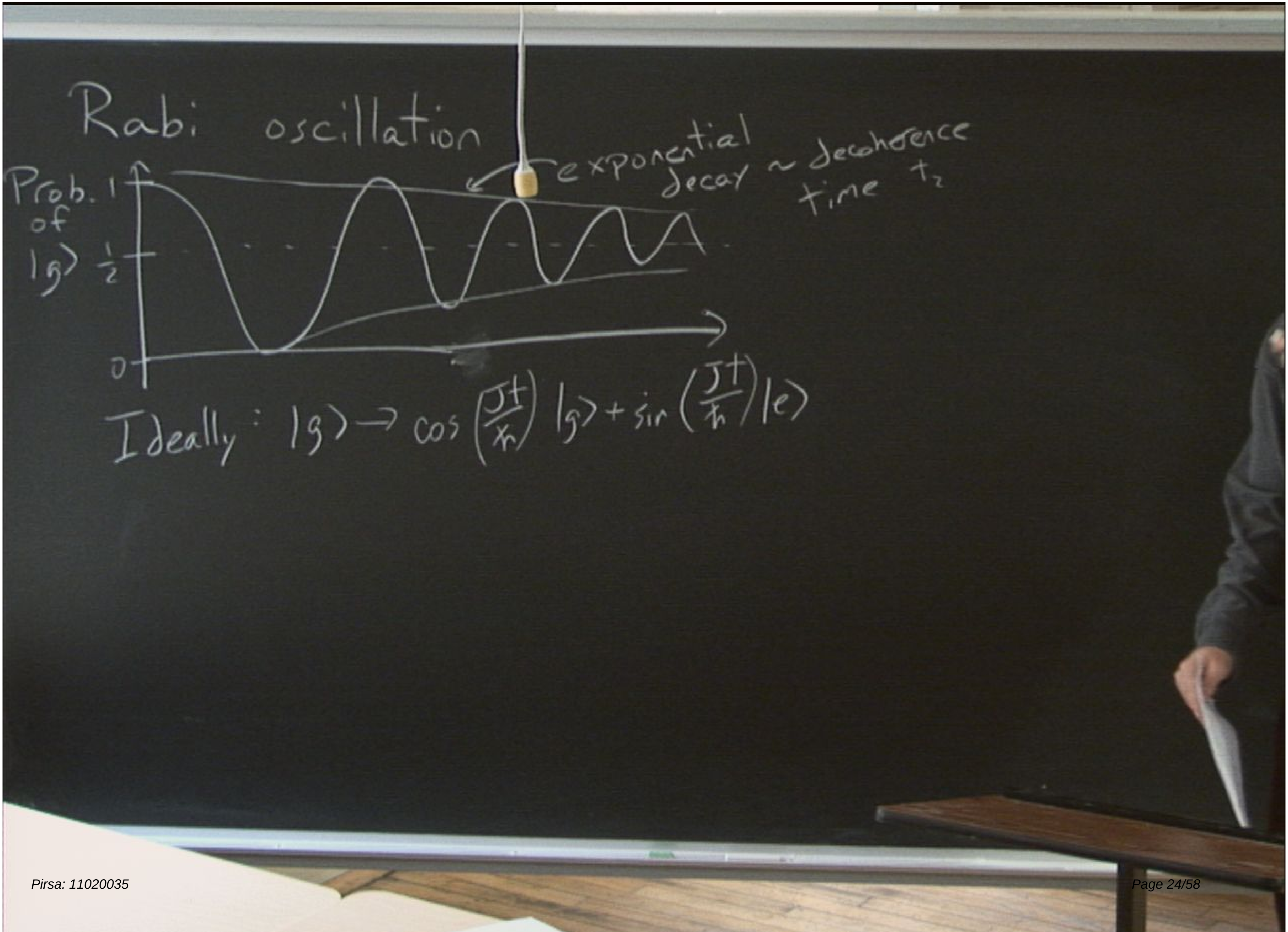
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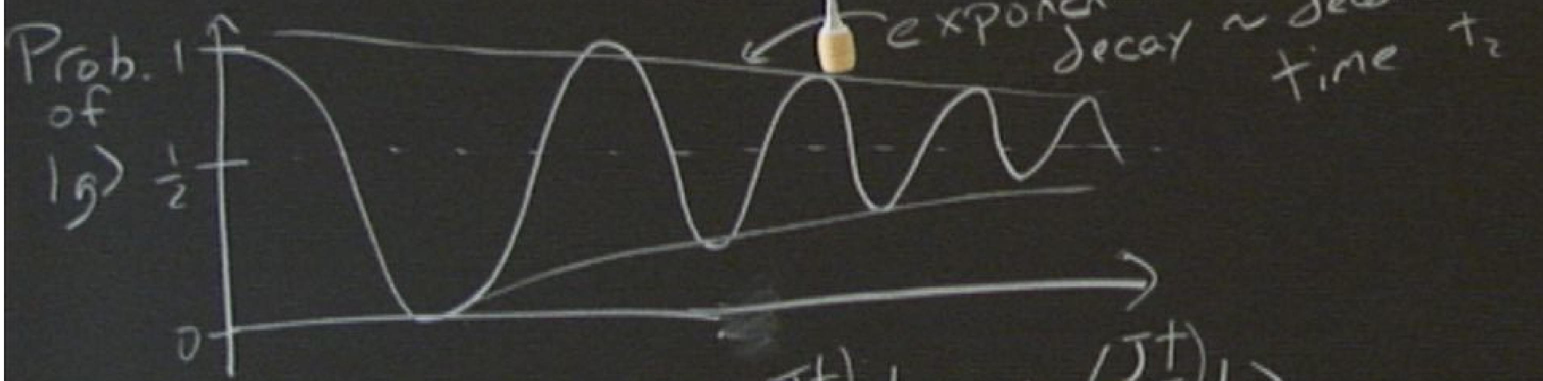

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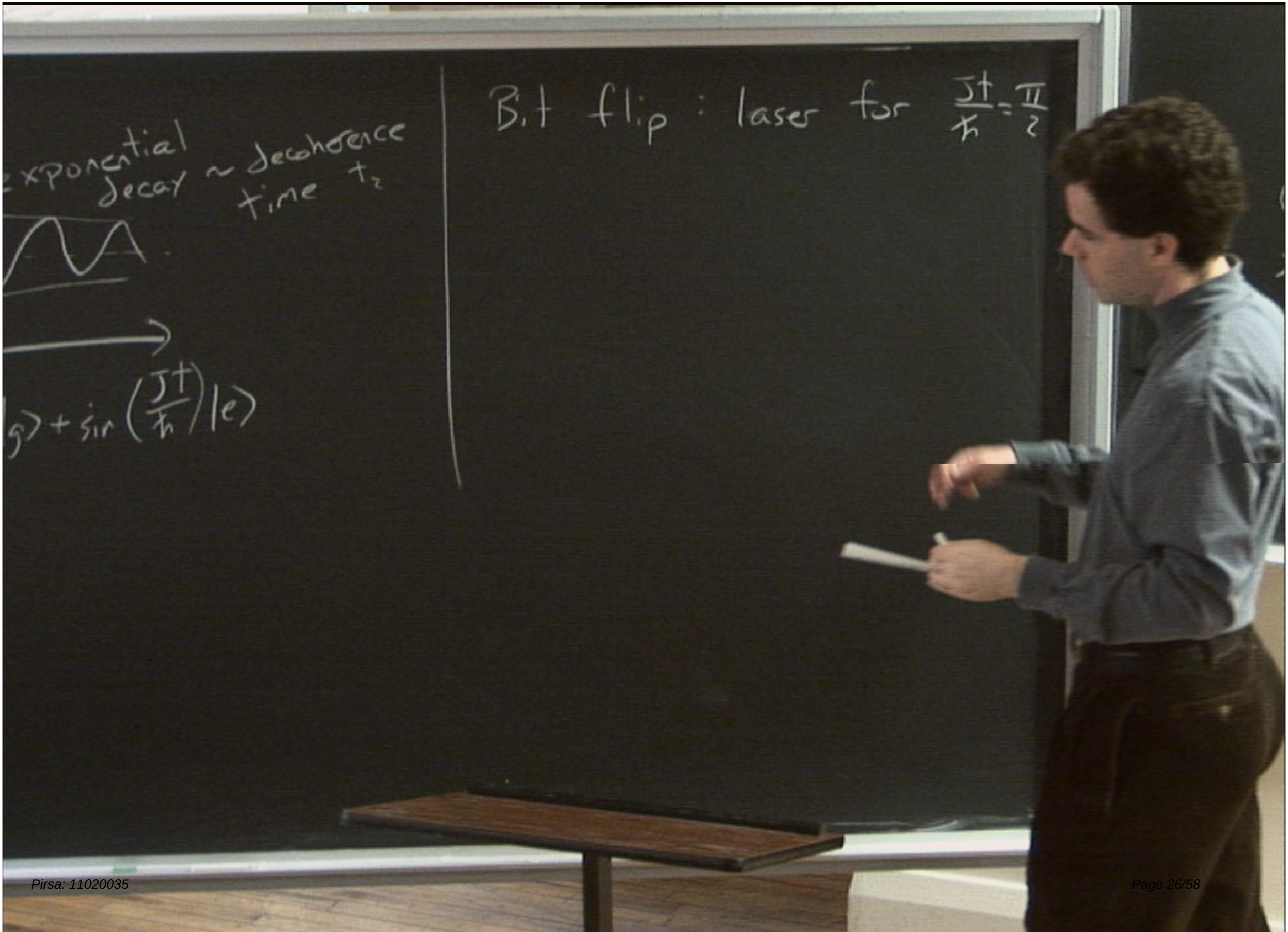
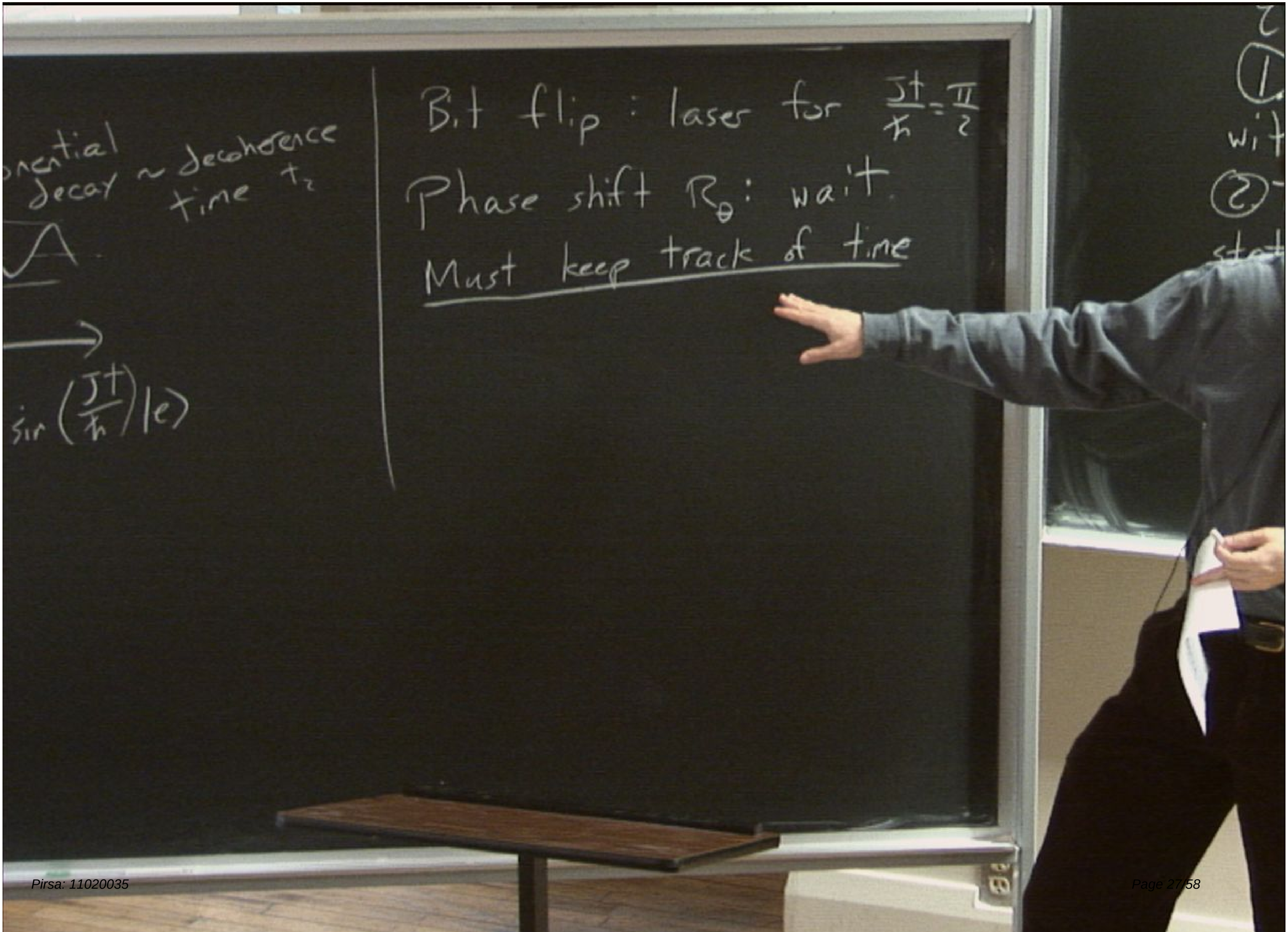

Bit flip : laser for $\frac{Jt}{\hbar} = \frac{\pi}{2}$
exponential decay ~ decoherence time t_2
$|g\rangle + \sin\left(\frac{Jt}{\hbar}\right)|e\rangle$


Bit flip : laser for $\frac{Jt}{\hbar} = \frac{\pi}{2}$
Phase shift R_θ : wait
Must keep track of time
decay ~ decoherence time t_2
$\sin\left(\frac{Jt}{\hbar}\right)|e\rangle$

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Phase shift R_θ : wait.

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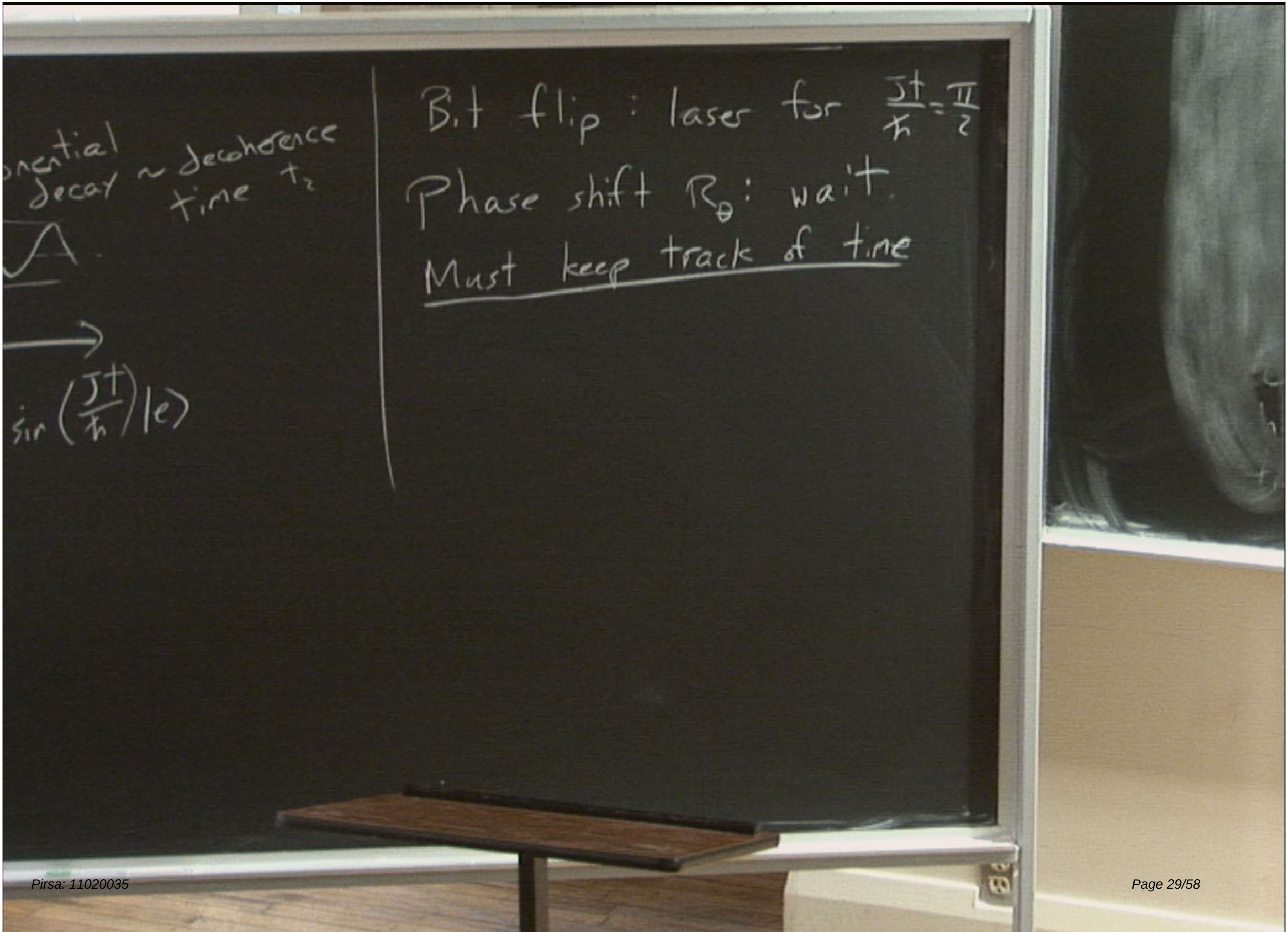
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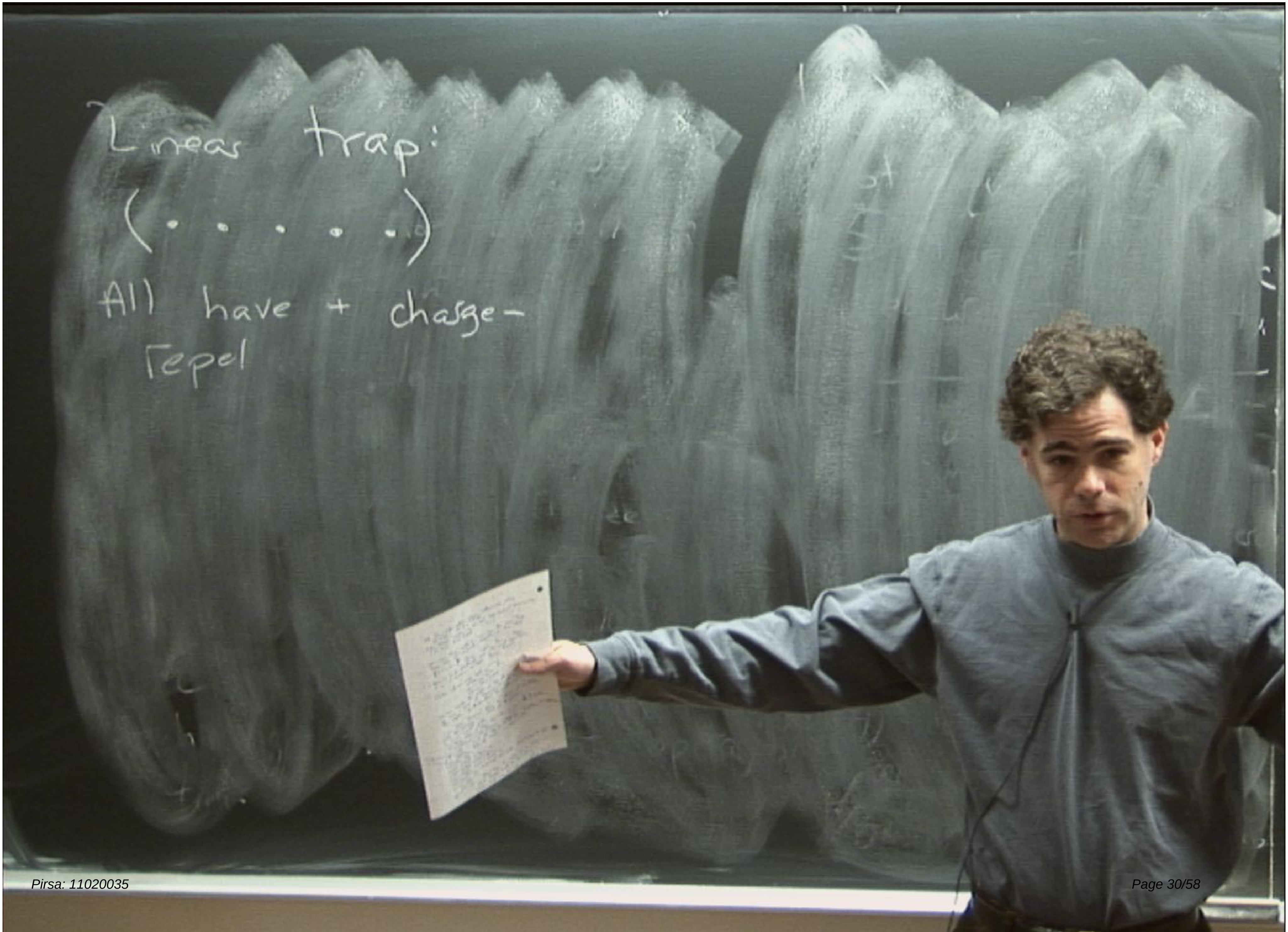
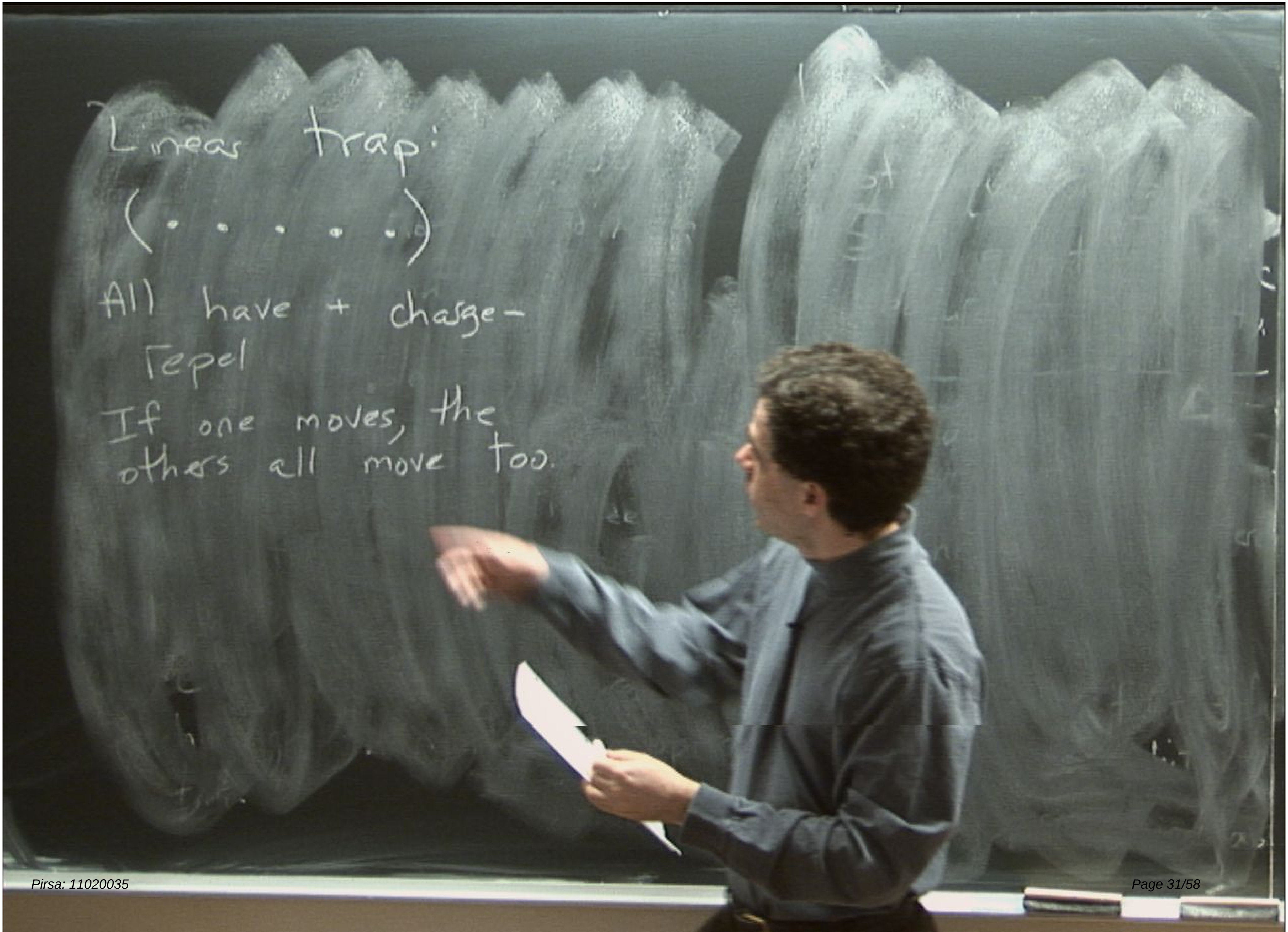

Linear trap:
All have + charge -
repel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If one moves, the
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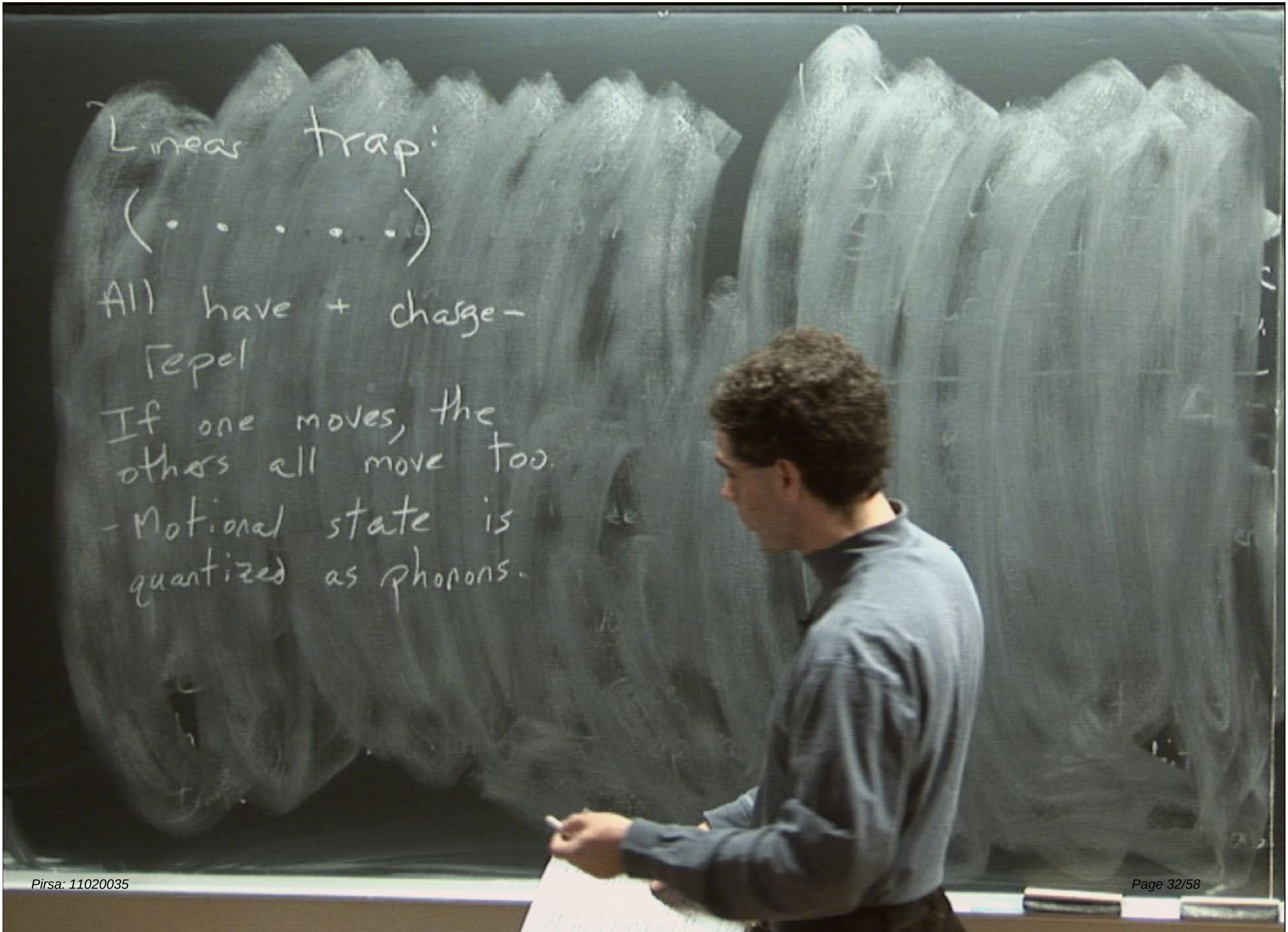
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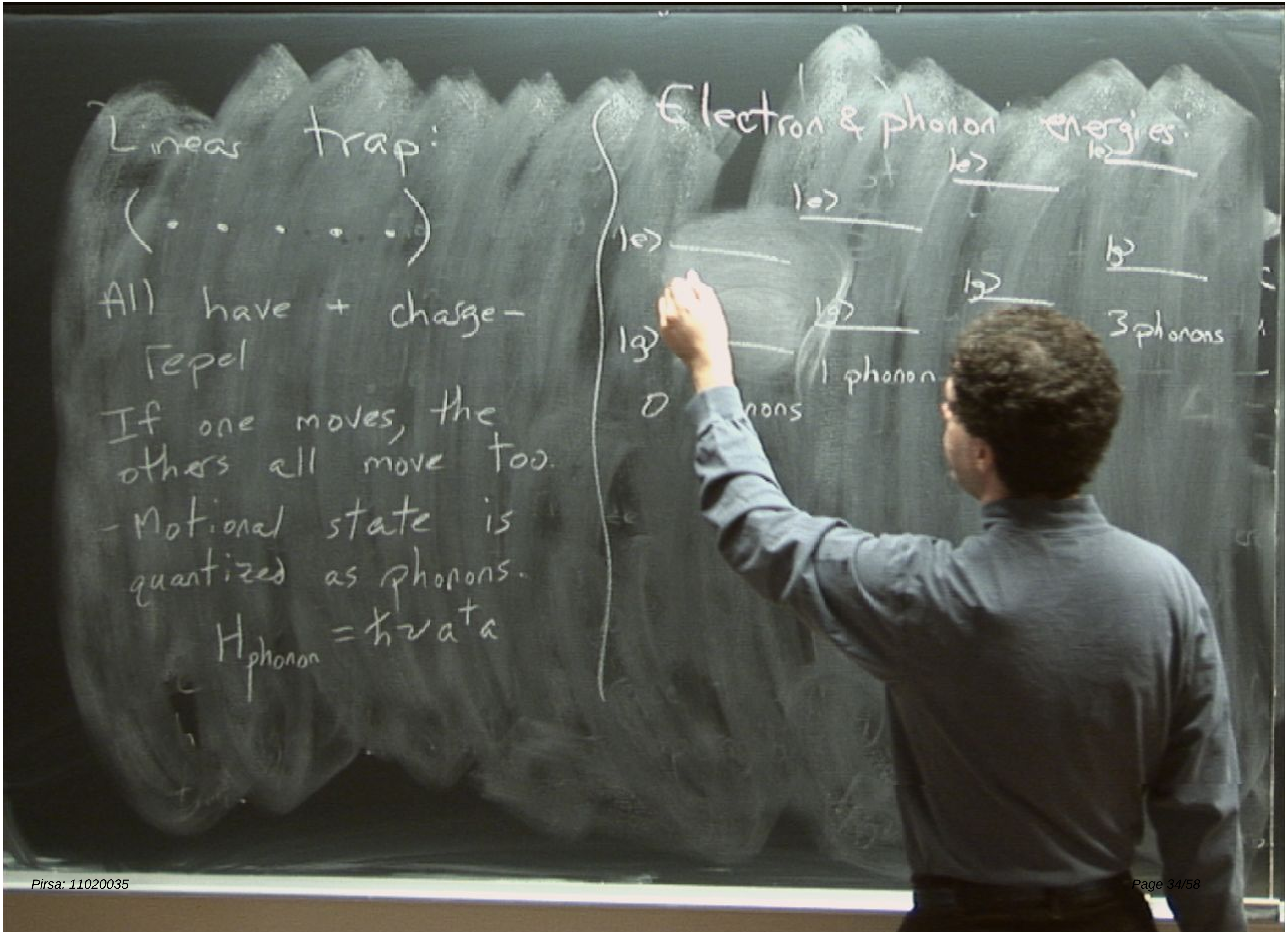
$$H_{phonon} = \hbar \nu a^{\dagger} a$$

Electron & phonon energies:

$|e\rangle$ ——

$|g\rangle$ ——

0 phonons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Electron & phonon energies:
|e⟩
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0 phonons
1 phonon
3 phonons

Linear trap:

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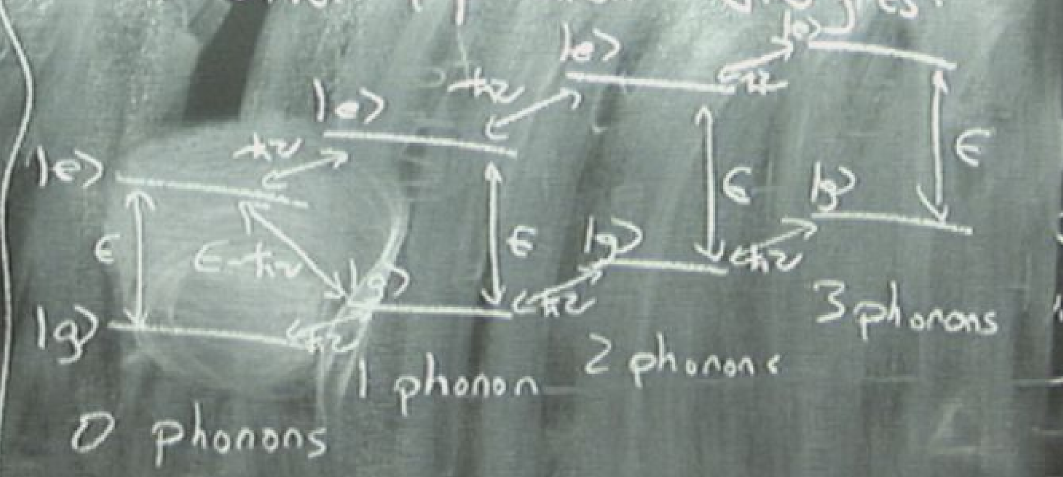

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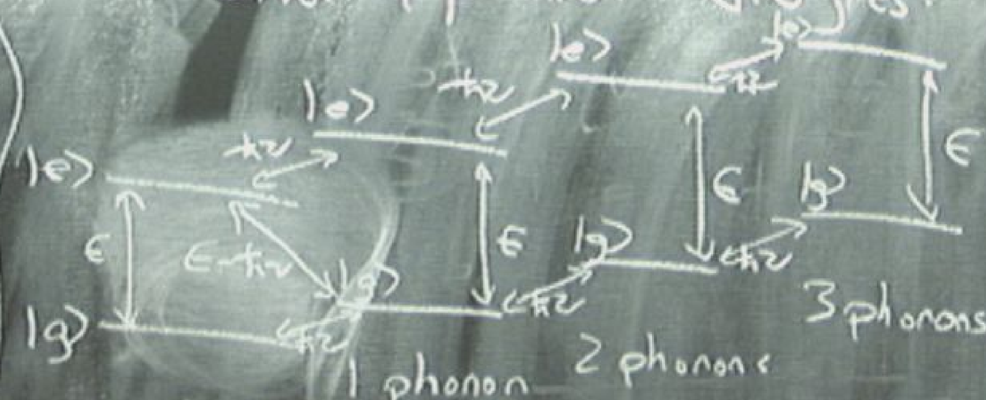

Laser w/ freq. $\epsilon - \hbar\nu$

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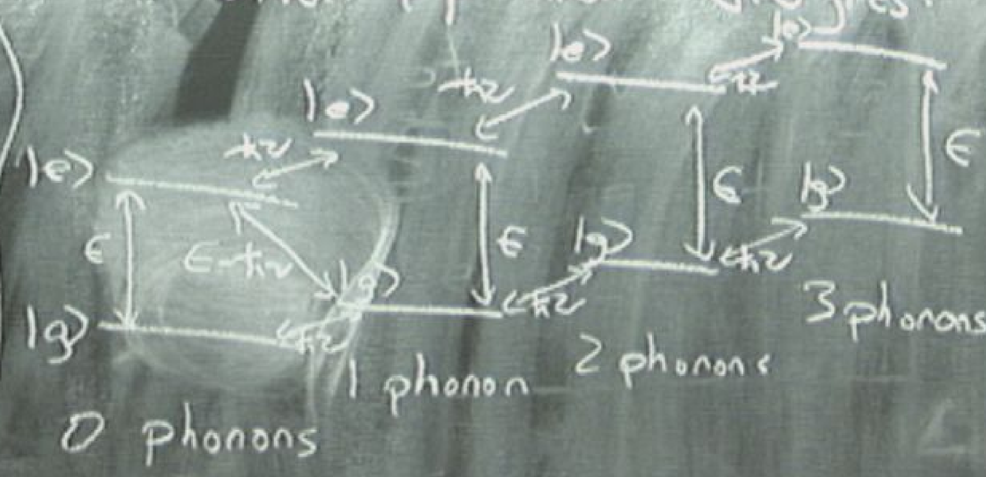
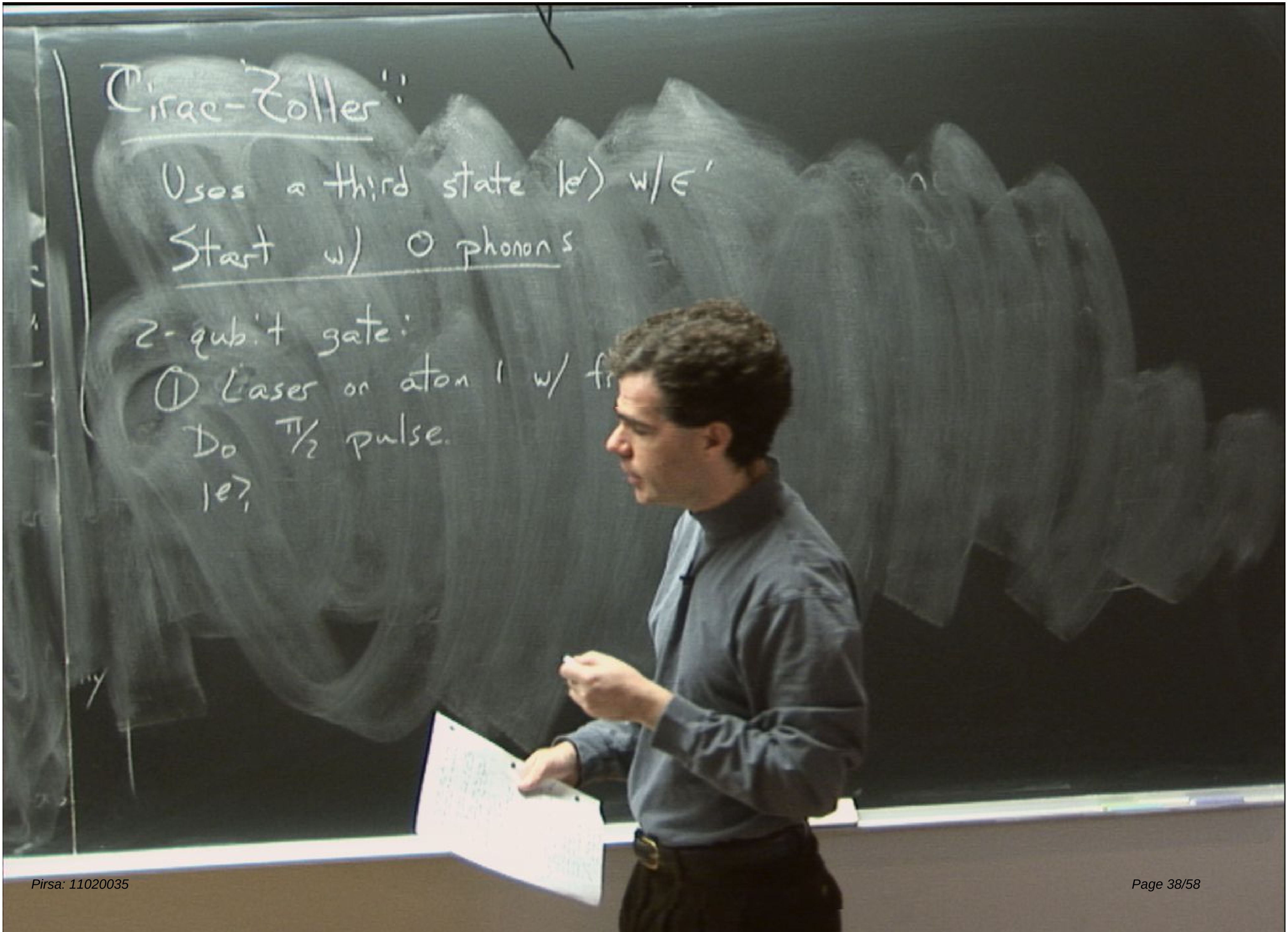


Laser w/ freq. $\epsilon - \hbar\nu$

Coup


Cirac-Zoller:
Uses a third state |e) w/ ϵ'
Start w/ 0 phonons
2-qubit gate:
1 Laser on atom 1 w/
Do π/2 pulse.
|e⟩

Cirac-Zoller:

Uses a third state $|e'\rangle$ w/ ϵ'

Start w/ 0 phonons

2-qubit gate:

① Laser on atom 1 w/ freq. $\epsilon - \hbar\nu$

Do $\pi/2$ pulse.

$|e\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |1\rangle_{phonon}$

$|g\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |0\rangle_{phonon}$

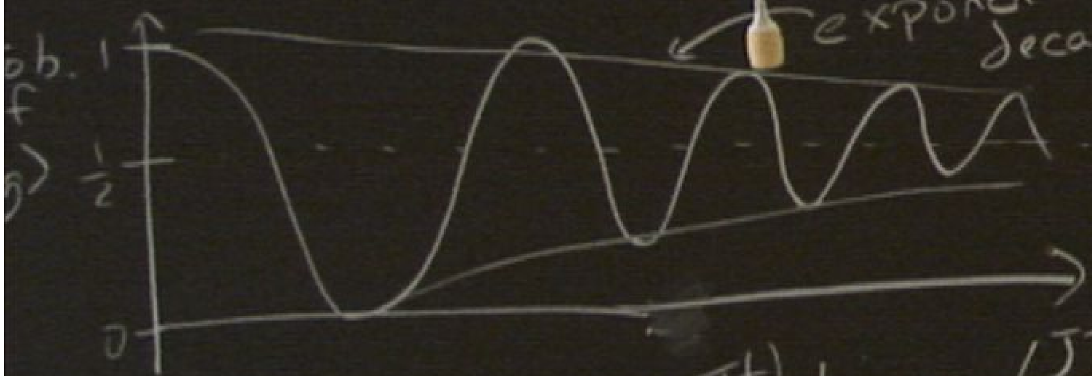
② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$

If $|g\rangle_2$, nothing happens.

If $|e\rangle_2 |0\rangle_{phonon}$, nothing happens

If $|e\rangle_2 |1\rangle_{phonon}$,

Rabi oscillation



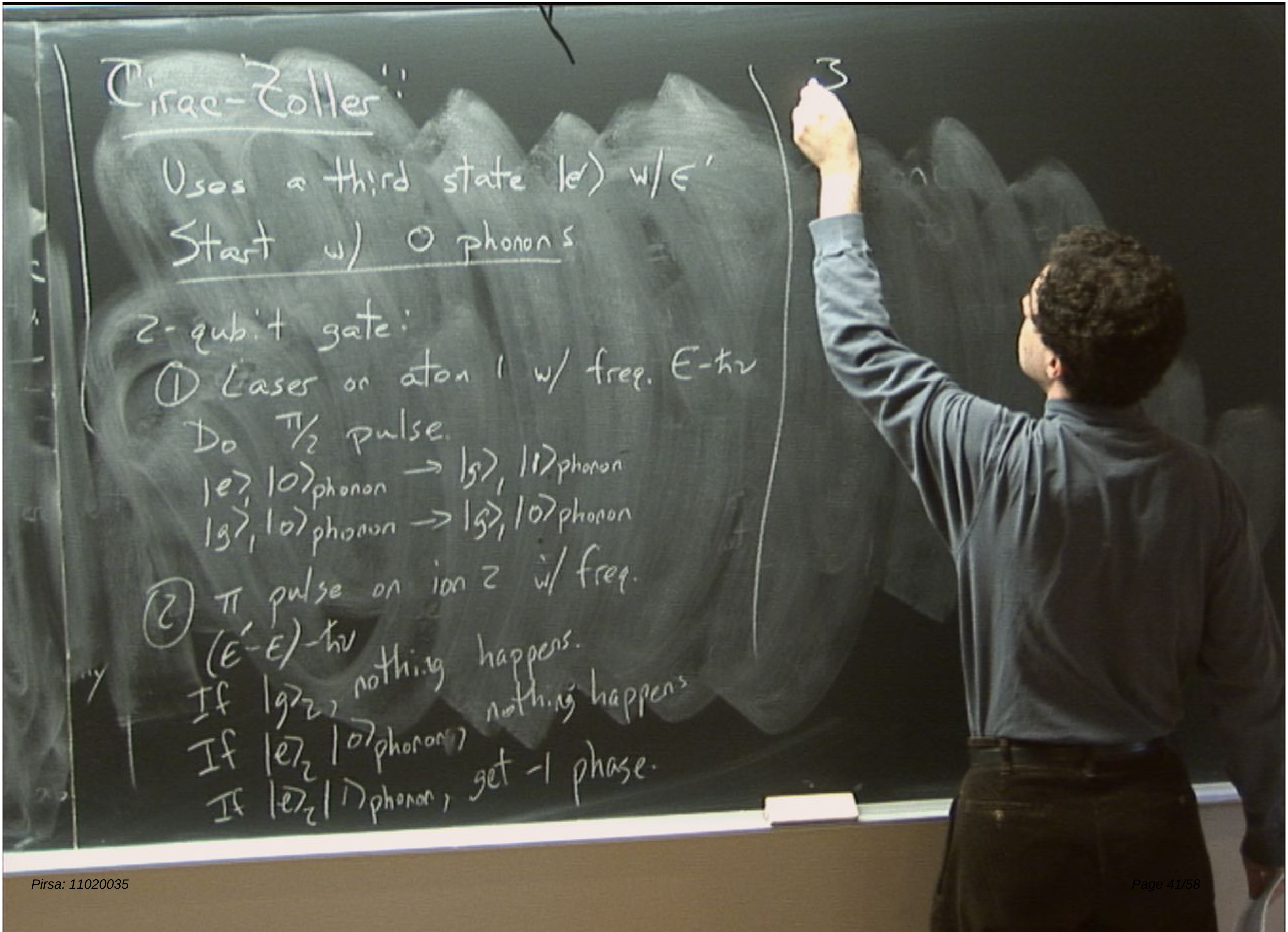
exponential decay ~ decoherence time t_2

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

Bit flip : |e

Phase shift

Must keep tr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Start w/ 0 phonons
2-qubit gate:
① Laser on atom 1 w/ freq. E-ħν
Do π/2 pulse.
|e⟩,|0⟩phonon → |g⟩,|1⟩phonon
|g⟩,|0⟩phonon → |g⟩,|0⟩phonon
② π pulse on ion 2 w/ freq. (E'-E)-ħν
If |g⟩2, nothing happens.
If |e⟩2 |0⟩phonon, nothing happens
If |e⟩2 |1⟩phonon, get -1 phase.
3

Cirac-Zoller:

Uses a third state $|e'\rangle$ w/ ϵ'

Start w/ 0 phonons

2-qubit gate:

① Laser on atom 1 w/ freq. $\epsilon - \hbar\nu$

Do $\pi/2$ pulse.

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② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$

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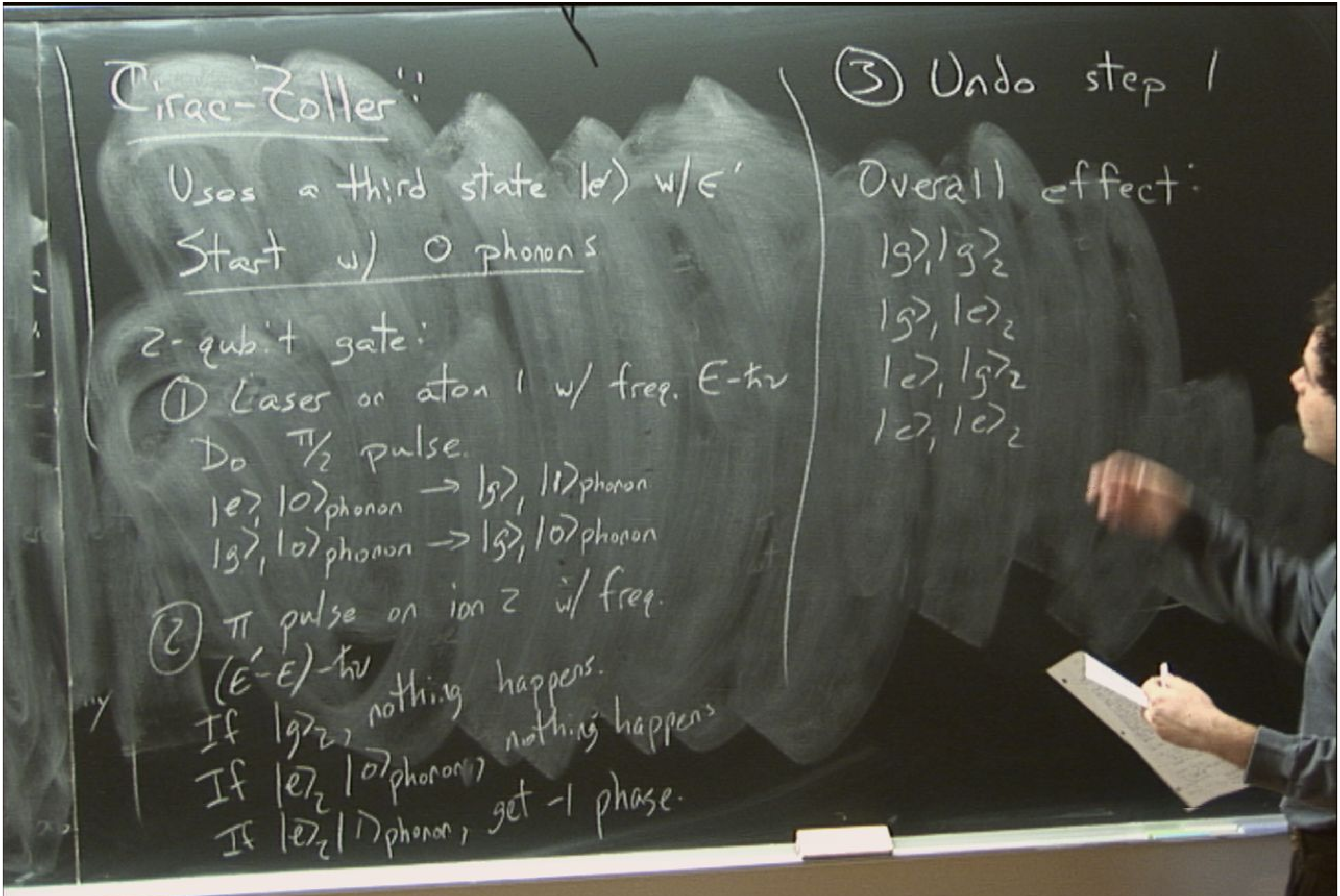
③ Undo step 1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2-qubit gate:
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Do $\pi/2$ pulse.
$|e\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |1\rangle_{phonon}$
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② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$
If $|g\rangle_2$, nothing happens.
If $|e\rangle_2 |0\rangle_{phonon}$, nothing happens
If $|e\rangle_2 |1\rangle_{phonon}$, get -1 phase.
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Overall effect:
$|g\rangle_1 |g\rangle_2$
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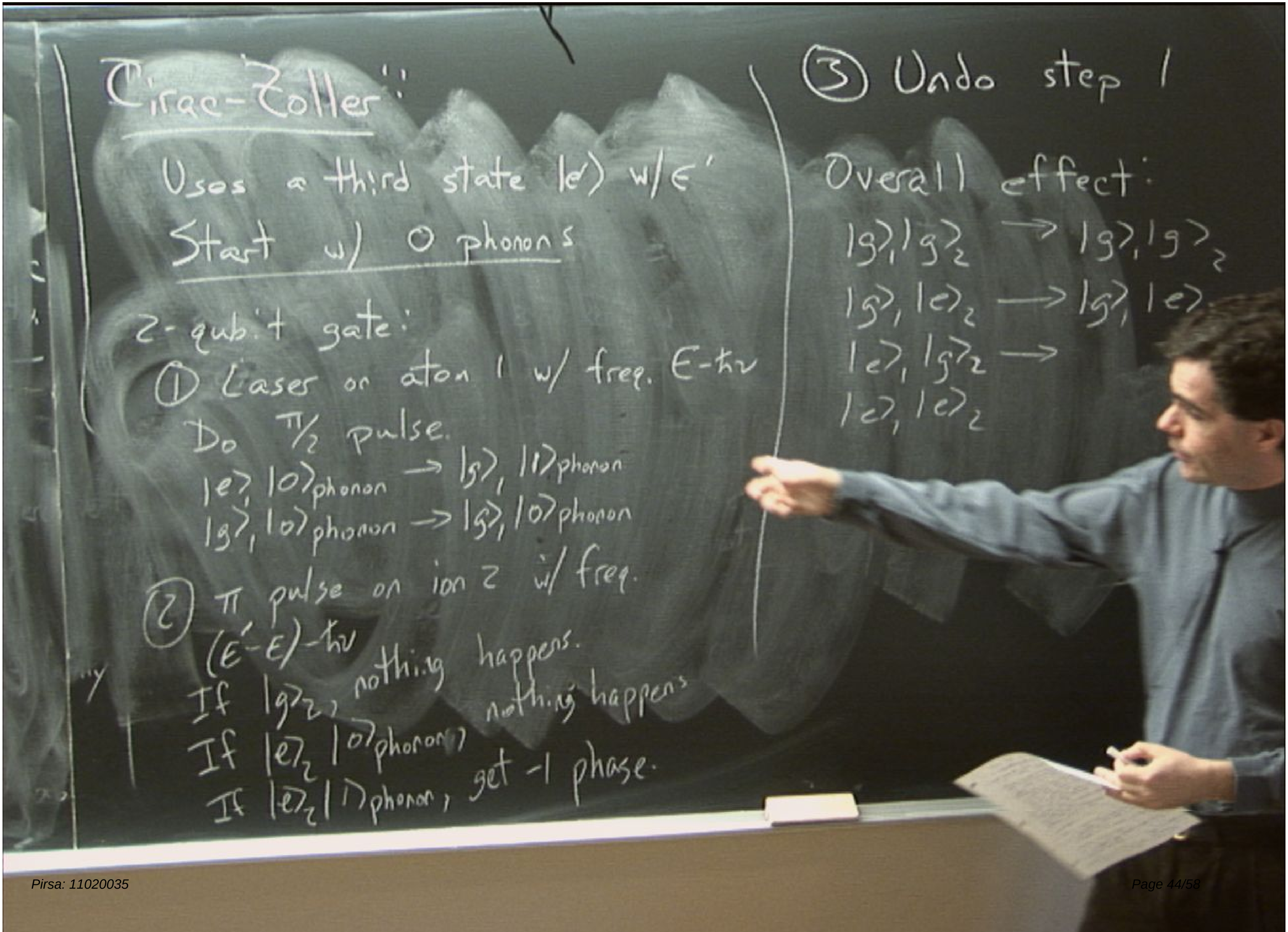
Cirac-Zoller:
Uses a third state |e') w/ ε'
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2-qubit gate:
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Do π/2 pulse.
|e>, |0>phonon → |g>, |1>phonon
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If |g>2, nothing happens.
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Overall effect:
|g>1 |g>2 → |g>1 |g>2
|g>1 |e>2 → |g>1 |e>2
|e>1 |g>2 →
|e>1 |e>2

Cirac-Zoller:

Uses a third state $|e\rangle$ w/ ϵ'

Start w/ 0 phonons

2-qubit gate:

① Laser on atom 1 w/ freq. $\epsilon - \hbar\nu$

Do $\pi/2$ pulse.

$|e\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |1\rangle_{phonon}$

$|g\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |0\rangle_{phonon}$

② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$

If $|g\rangle_2$, nothing happens.

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③ Undo step 1

Overall effect:

$|g\rangle_1 |g\rangle_2 \rightarrow |g\rangle_1 |g\rangle_2$

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$|e\rangle_1 |e\rangle_2 \rightarrow$

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Overall effect:

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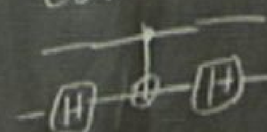
$|e\rangle_1 |g\rangle_2 \rightarrow |e\rangle_1 |g\rangle_2$

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

controlled-phase gate



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② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$

If $|g\rangle_2$, nothing happens.

If $|e\rangle_2 |0\rangle_{phonon}$, nothing happens

If $|e\rangle_2 |1\rangle_{phonon}$, get -1 phase.

③ Undo step 1

Overall effect:

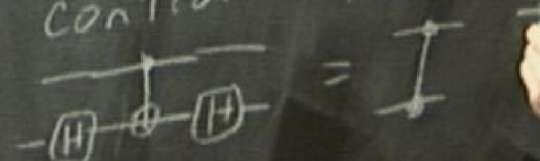
$|g\rangle_1 |g\rangle_2 \rightarrow |g\rangle_1 |g\rangle_2$

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

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

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

controlled-phase gate



Cirac-Zoller:

Uses a third state $|e\rangle$ w/ ϵ'

Start w/ 0 phonons

2-qubit gate:

① Laser on atom 1 w/ freq. $\epsilon - \hbar\nu$

Do $\pi/2$ pulse.

$|e\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |1\rangle_{phonon}$

$|g\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |0\rangle_{phonon}$

② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$

If $|g\rangle_2$, nothing happens.

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Overall effect:

$|g\rangle_1 |g\rangle_2 \rightarrow |g\rangle_1 |g\rangle_2$

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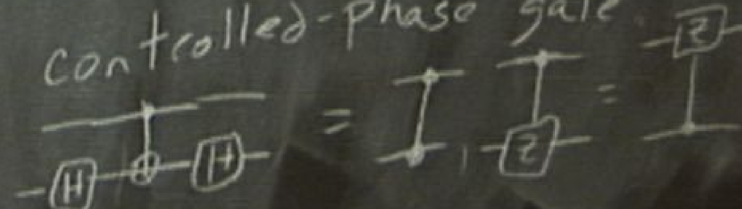
$|e\rangle_1 |g\rangle_2 \rightarrow |e\rangle_1 |g\rangle_2$

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

controlled-phase gate.



Cirac-Zoller:

Uses a third state $|e'\rangle$ w/ ϵ'

Start w/ 0 phonons

2-qubit gate:

① Laser on atom 1 w/ freq. $\epsilon - \hbar\nu$

Do $\pi/2$ pulse.

$|e\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |1\rangle_{phonon}$

$|g\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |0\rangle_{phonon}$

② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$

If $|g\rangle_2$, nothing happens.

If $|e\rangle_2 |0\rangle_{phonon}$, nothing happens

If $|e\rangle_2 |1\rangle_{phonon}$, get -1 phase.

③ Undo step 1

Overall effect:

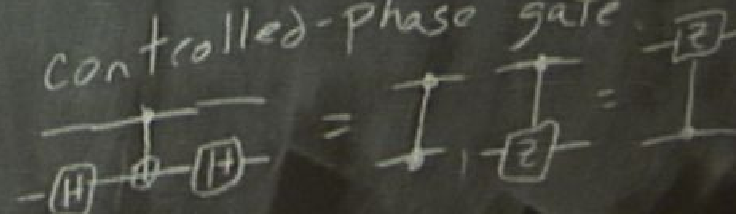
$|g\rangle_1 |g\rangle_2 \rightarrow |g\rangle_1 |g\rangle_2$

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

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

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

controlled-phase gate.



Universal set of gates

Cirac-Zoller:

Uses a third state $|e\rangle$ w/ ϵ'

Start w/ 0 phonons

2-qubit gate:

① Laser on atom 1 w/ freq. $\epsilon - \hbar\nu$

Do $\pi/2$ pulse.

$|e\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |1\rangle_{phonon}$

$|g\rangle_1 |0\rangle_{phonon} \rightarrow |g\rangle_1 |0\rangle_{phonon}$

② π pulse on ion 2 w/ freq. $(\epsilon' - \epsilon) - \hbar\nu$

If $|g\rangle_2$, nothing happens.

If $|e\rangle_2 |0\rangle_{phonon}$, nothing happens

If $|e\rangle_2 |1\rangle_{phonon}$, get -1 phase.

③ Undo step 1

Overall effect:

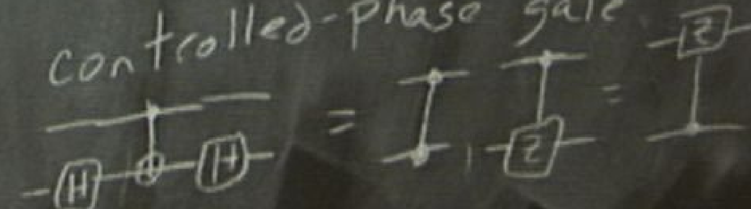
$|g\rangle_1 |g\rangle_2 \rightarrow |g\rangle_1 |g\rangle_2$

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

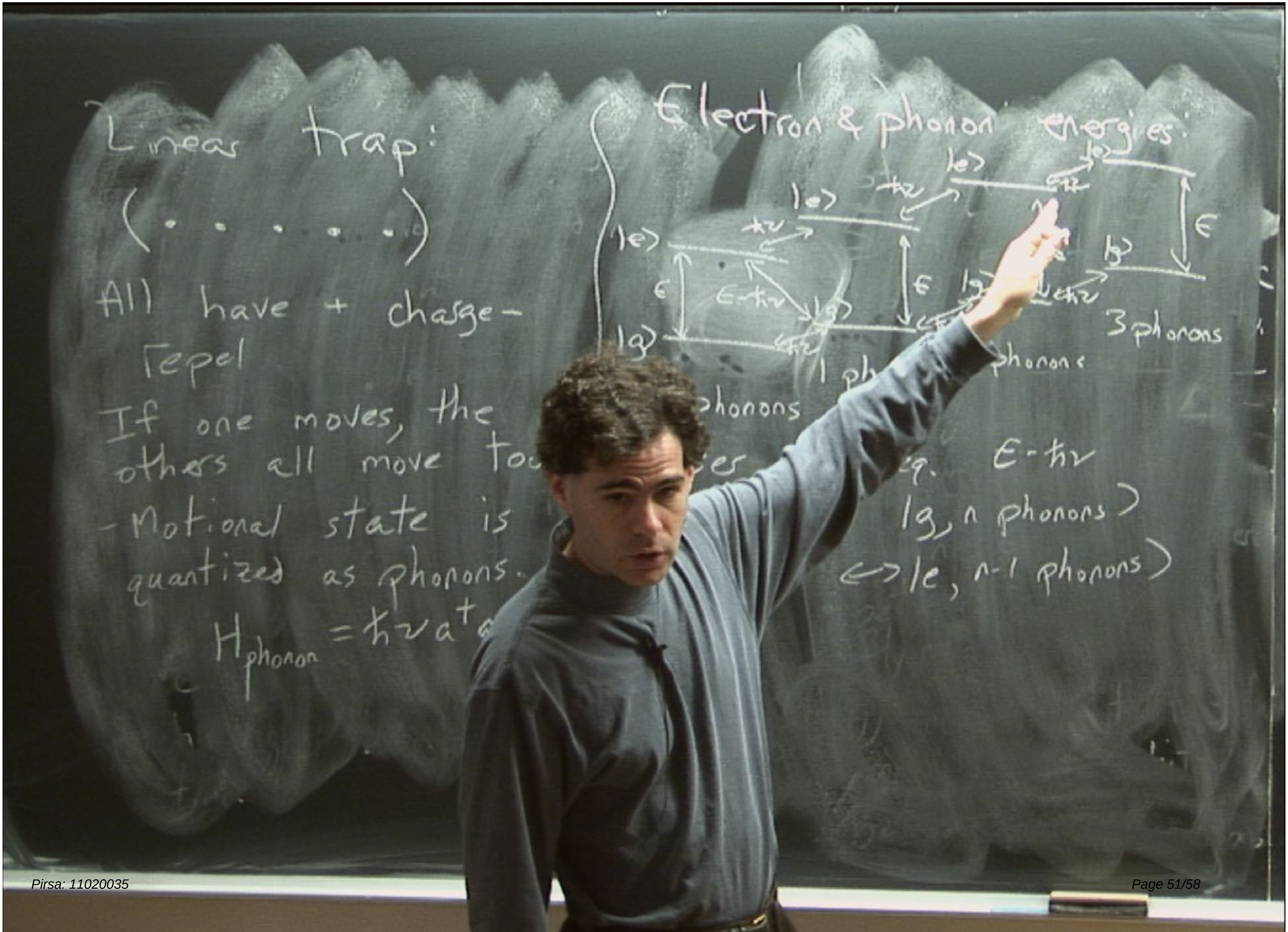
$|e\rangle_1 |g\rangle_2 \rightarrow |e\rangle_1 |g\rangle_2$

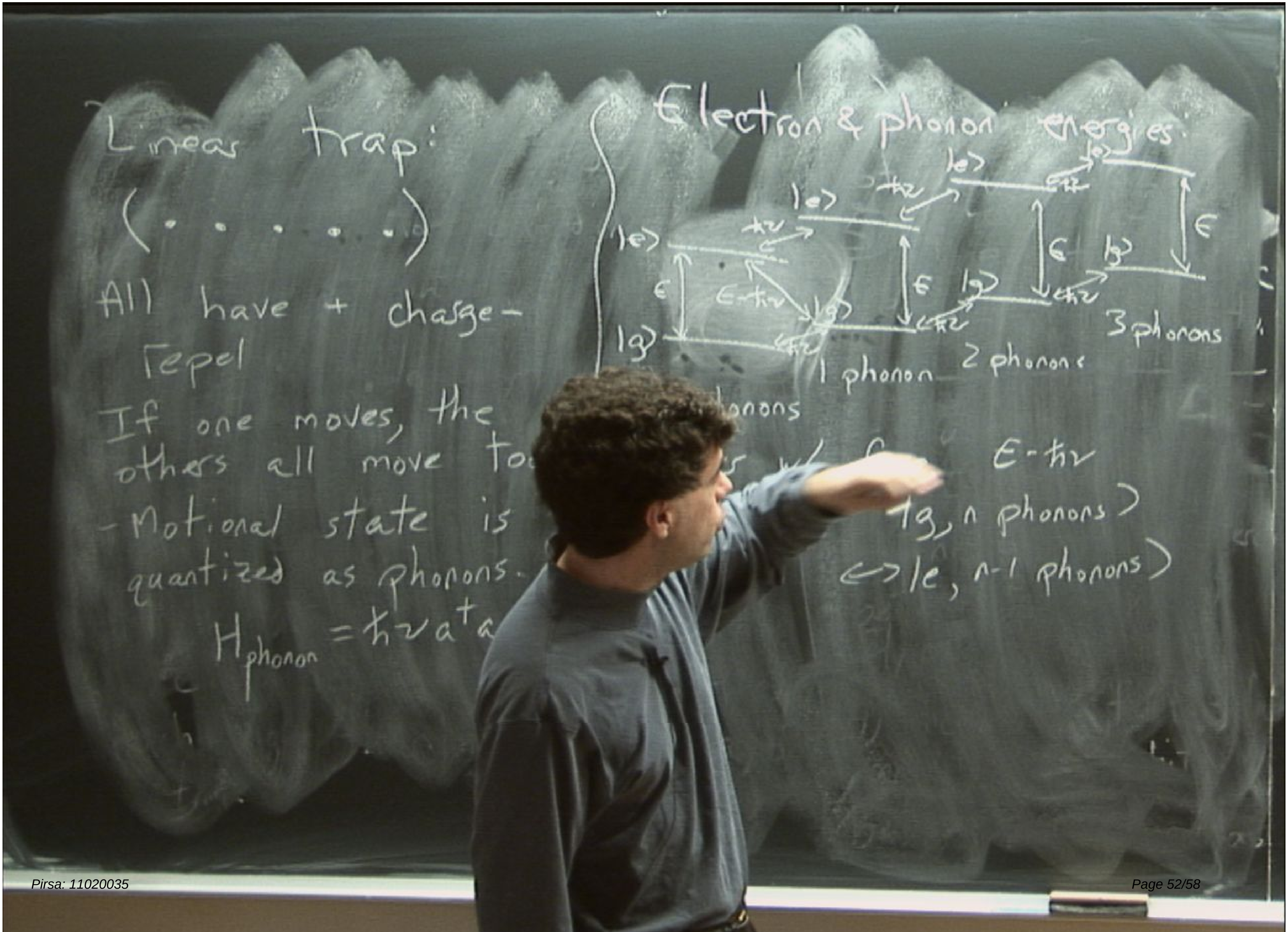
$|e\rangle_1 |e\rangle_2 \rightarrow -|e\rangle_1 |e\rangle_2$

controlled-phase gate



Universal set of gates


Linear trap:
All have + charge - repel
If one moves, the others all move
Motional state is
quantized as phonons.
$H_{phonon} = \hbar\nu a^\dagger$
Electron & phonon energies:
$|e\rangle$
$|g\rangle$
ϵ
$\epsilon - \hbar\nu$
$\hbar\nu$
3 phonons
phonons
$\epsilon - \hbar\nu$
$|g, n \text{ phonons}\rangle$
$\leftrightarrow |e, n-1 \text{ phonons}\rangle$


Linear trap:
All have + charge - repel
If one moves, the
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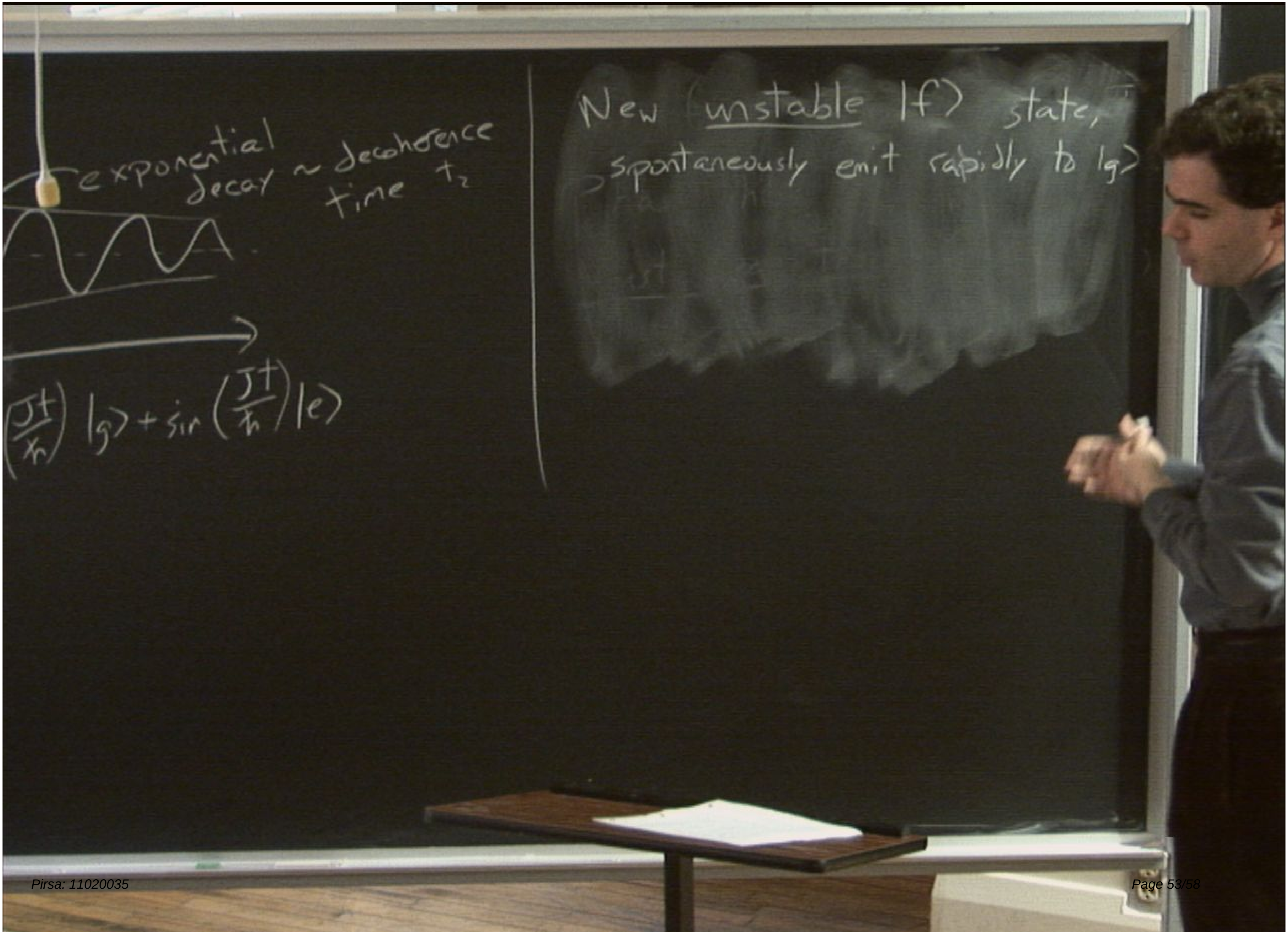
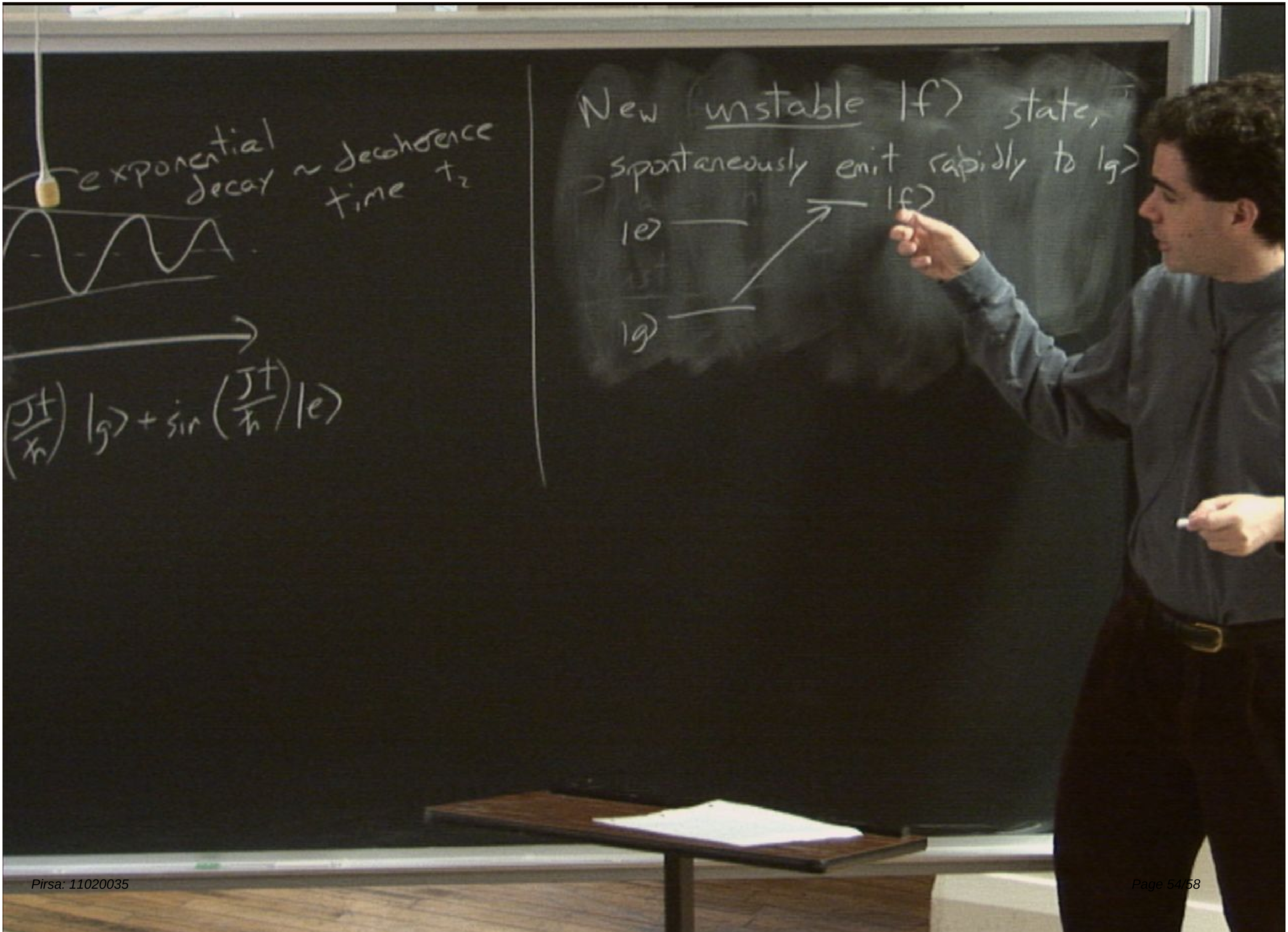
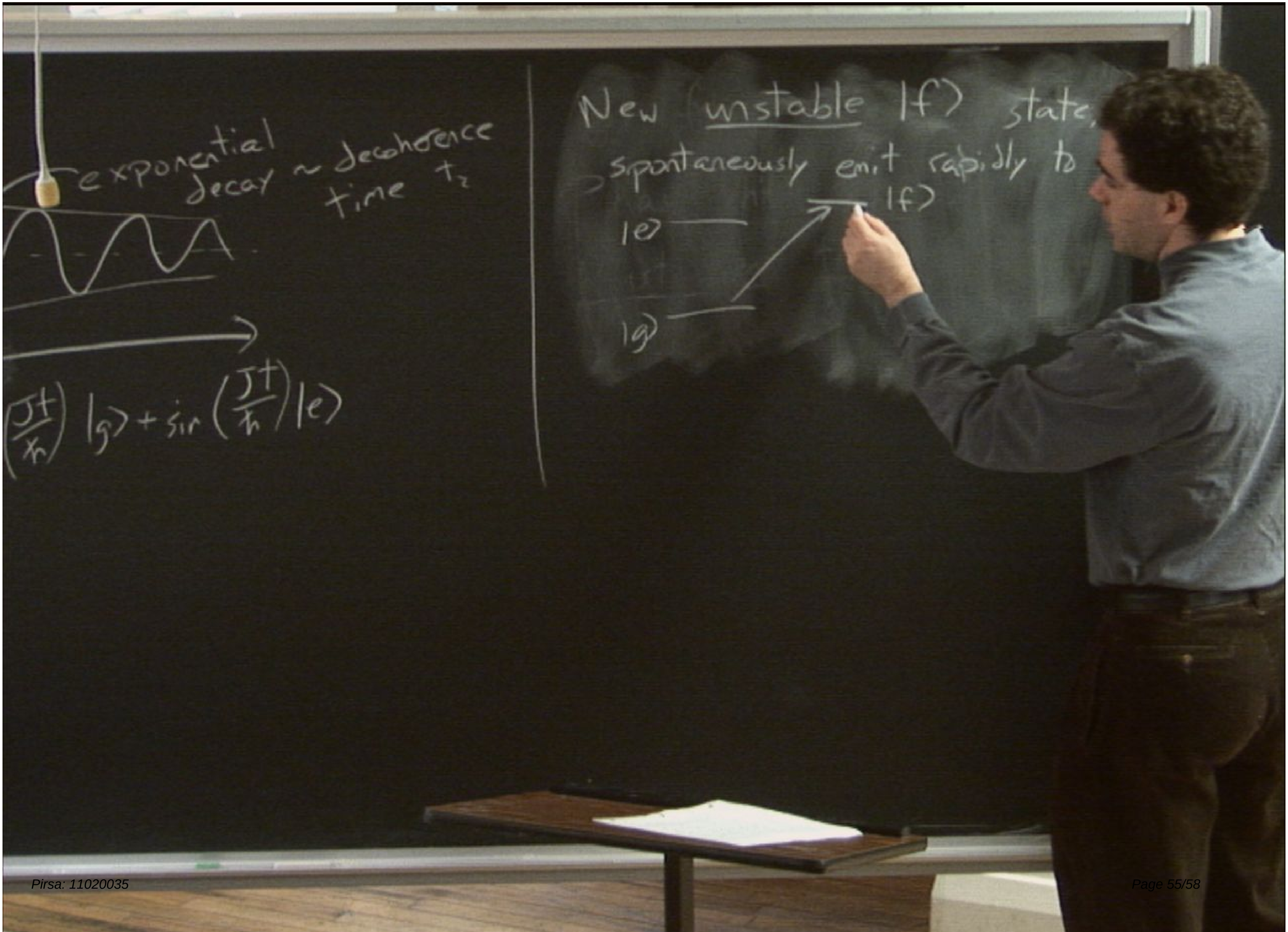
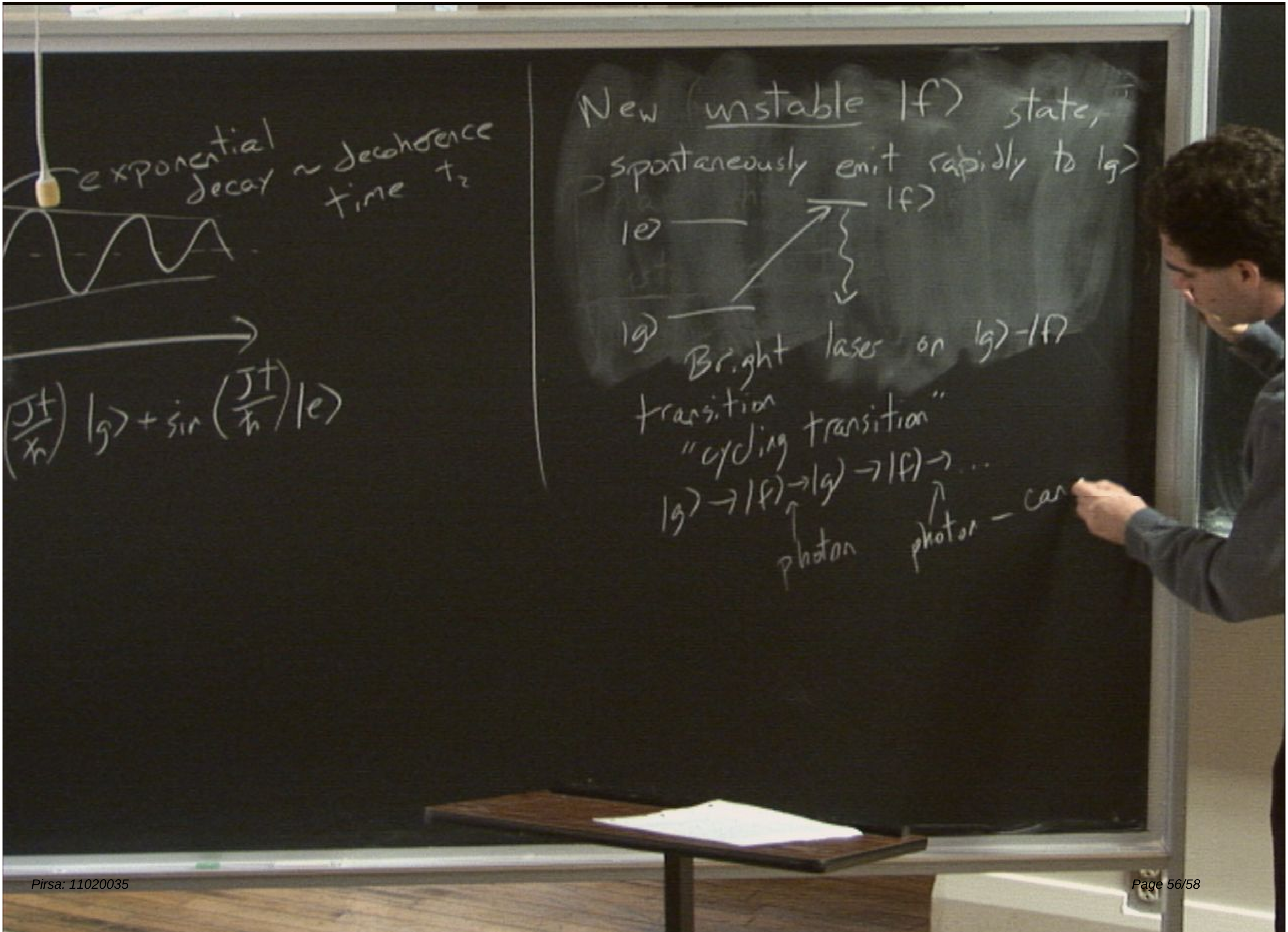
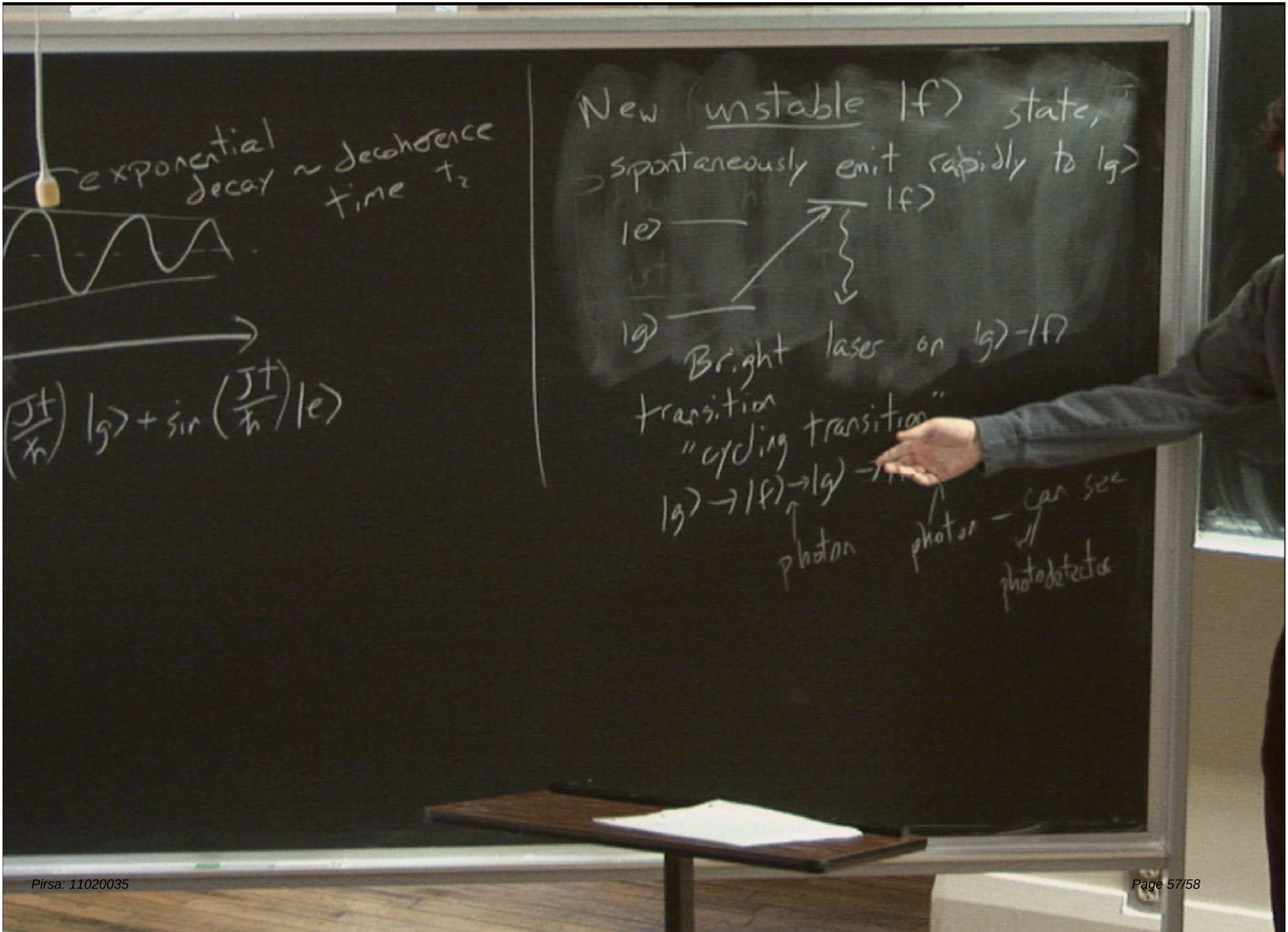
Motional state is
quantized as phonons.
$H_{phonon} = \hbar\nu a^\dagger a$
Electron & phonon energies:
$|e\rangle$
$|g\rangle$
ϵ
$\hbar\nu$
$\epsilon - \hbar\nu$
1 phonon
2 phonons
3 phonons
$\epsilon - \hbar\nu$
$|g, n$ phonons$\rangle$
$\leftrightarrow |e, n-1$ phonons$\rangle$


exponential decay ~ decoherence time t2
New (unstable |f> state,
spontaneously emit rapidly to |g>
(Jt/ħ) |g> + sin (Jt/ħ) |e>


exponential decay ~ decoherence time t_2
$\left(\frac{Jt}{\hbar}\right)|g\rangle + \sin\left(\frac{Jt}{\hbar}\right)|e\rangle$
New unstable $|f\rangle$ state,
spontaneously emit rapidly to $|g\rangle$
$|f\rangle$
$|e\rangle$
$|g\rangle$


exponential decay ~ decoherence time t2
New (unstable |f> state,
spontaneously emit rapidly to
|f>
|e>
|g>
(Jt/ħ) |g> + sin (Jt/ħ) |e>


exponential decay ~ decoherence time t_2
$\cos\left(\frac{Jt}{\hbar}\right)|g\rangle + \sin\left(\frac{Jt}{\hbar}\right)|e\rangle$
New unstable $|f\rangle$ state,
spontaneously emit rapidly to $|g\rangle$
$|f\rangle$
$|e\rangle$
$|g\rangle$
Bright lasers on $|g\rangle - |f\rangle$ transition
"cycling transition"
$|g\rangle \to |f\rangle \to |g\rangle \to |f\rangle \to \ldots$
photon
photon - can


exponential decay ~ decoherence time t_2
$\left(\frac{Jt}{\hbar}\right)|g\rangle + \sin\left(\frac{Jt}{\hbar}\right)|e\rangle$
New (unstable $|f\rangle$ state,
spontaneously emit rapidly to $|g\rangle$
$|f\rangle$
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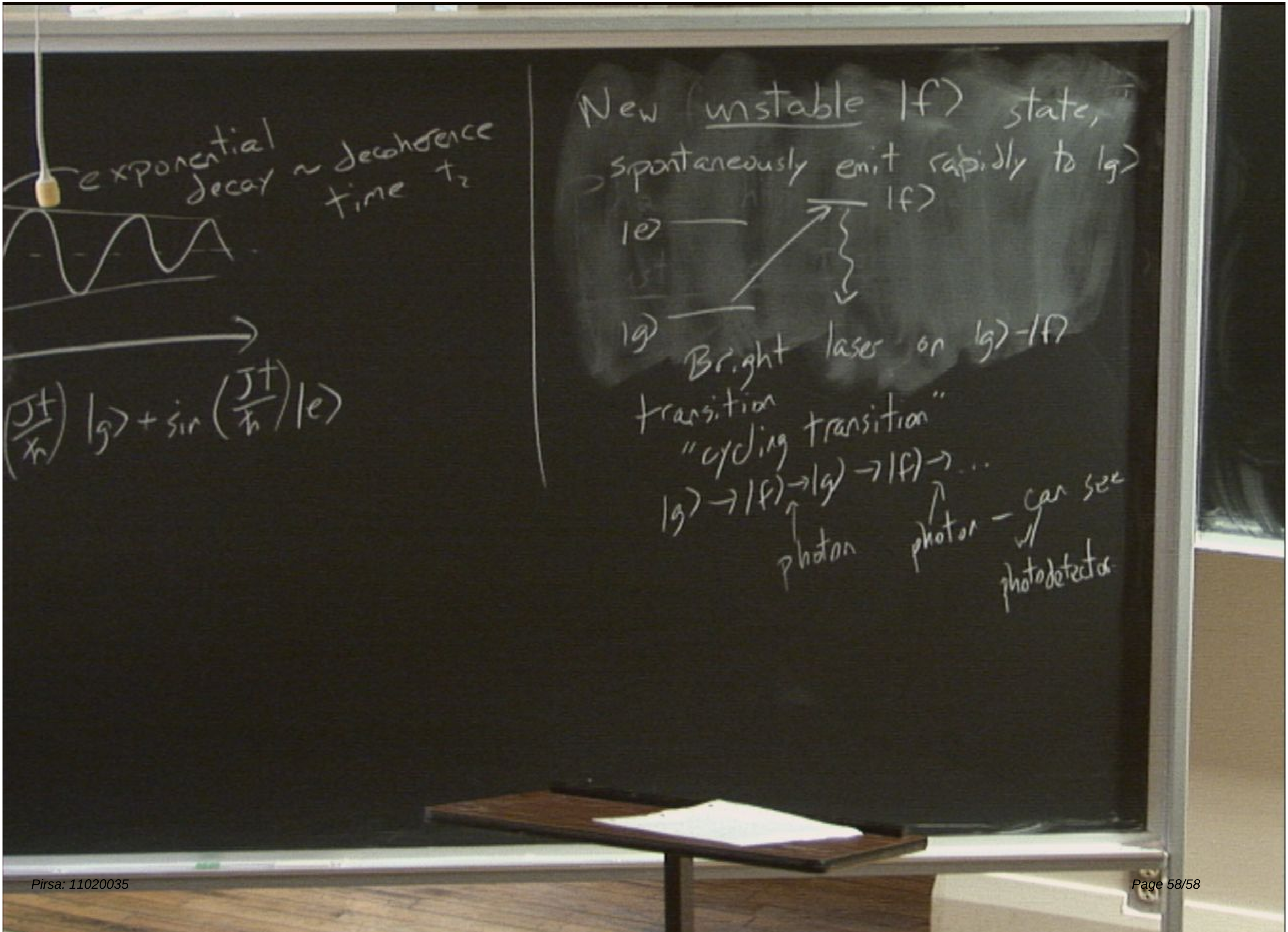
$|g\rangle$
Bright lasers on $|g\rangle-|f\rangle$
transition
"cycling transition"
$|g\rangle \to |f\rangle \to |g\rangle \to$
photon
photon - can see w/ photodetector


exponential decay ~ decoherence time t2
(Jt/ħ) |g> + sin (Jt/ħ) |e>
New (unstable |f> state,
spontaneously emit rapidly to |g>
|f>
|e>
|g>
Bright laser on |g>-|f> transition
"cycling transition"
|g> → |f> → |g> → |f> → ...
photon
photon - can see w/ photodetector