Title: Quantum Foundations Lecture

Speakers: Lucien Hardy

Collection: Quantum Foundations

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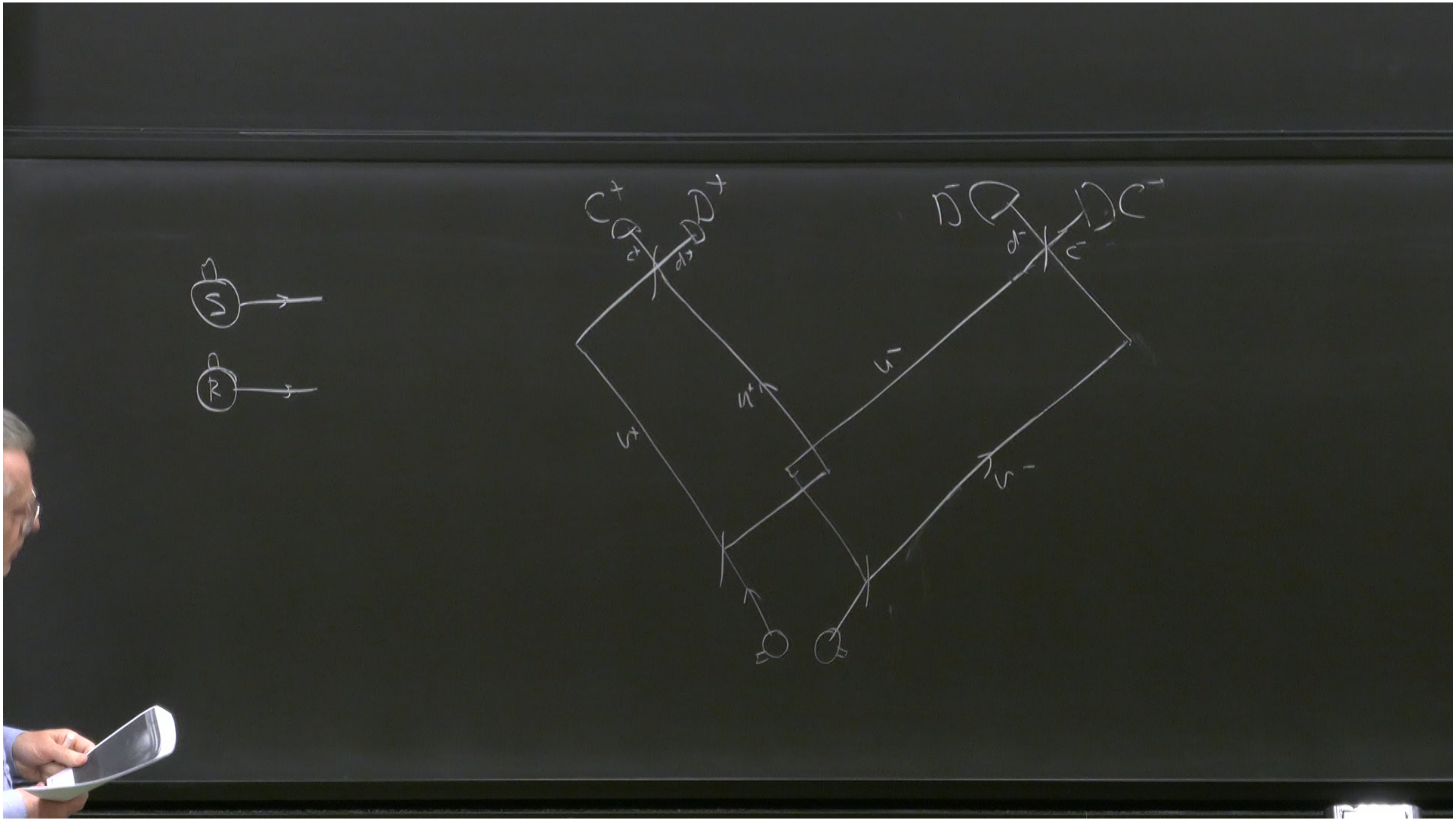
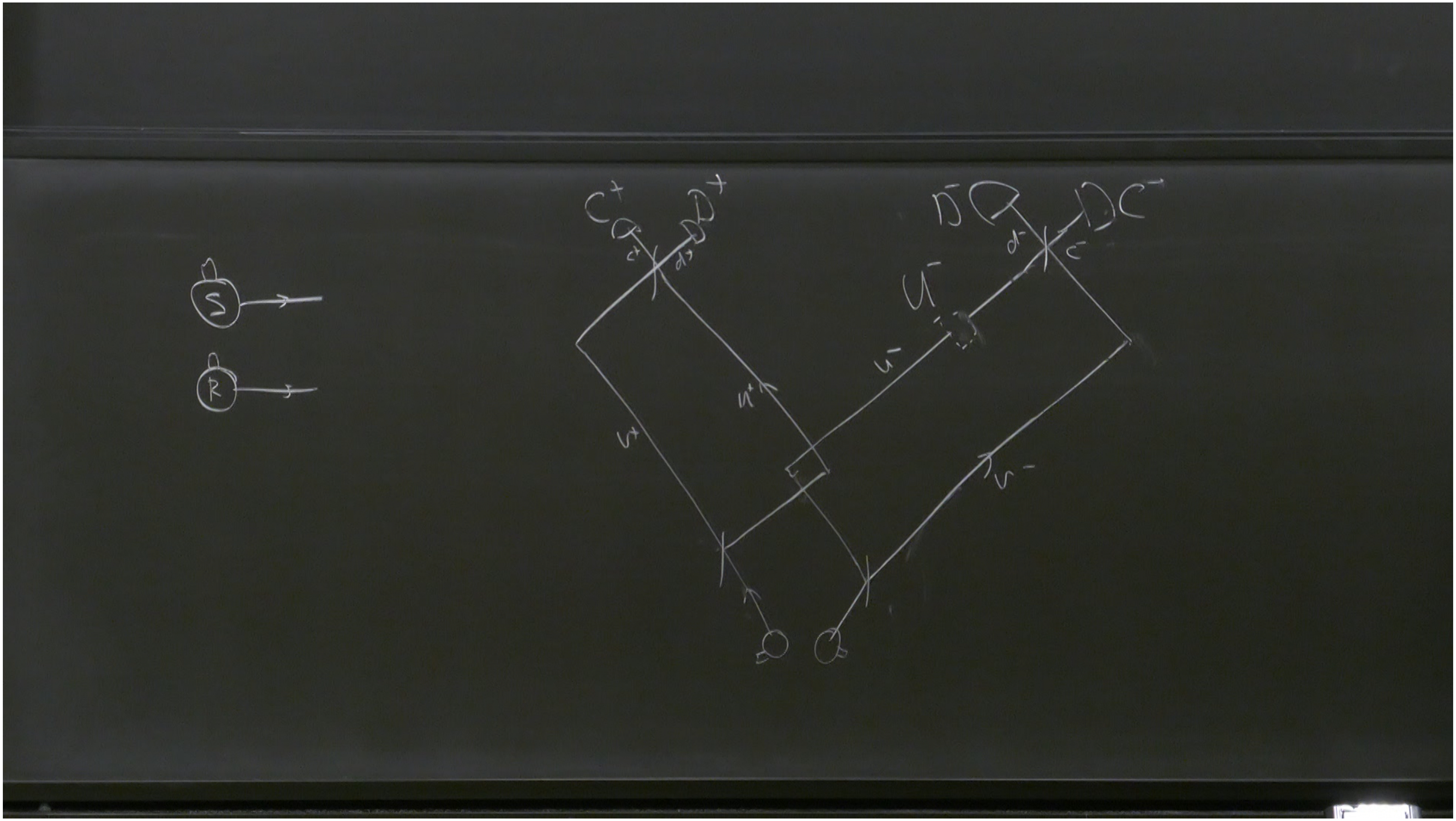
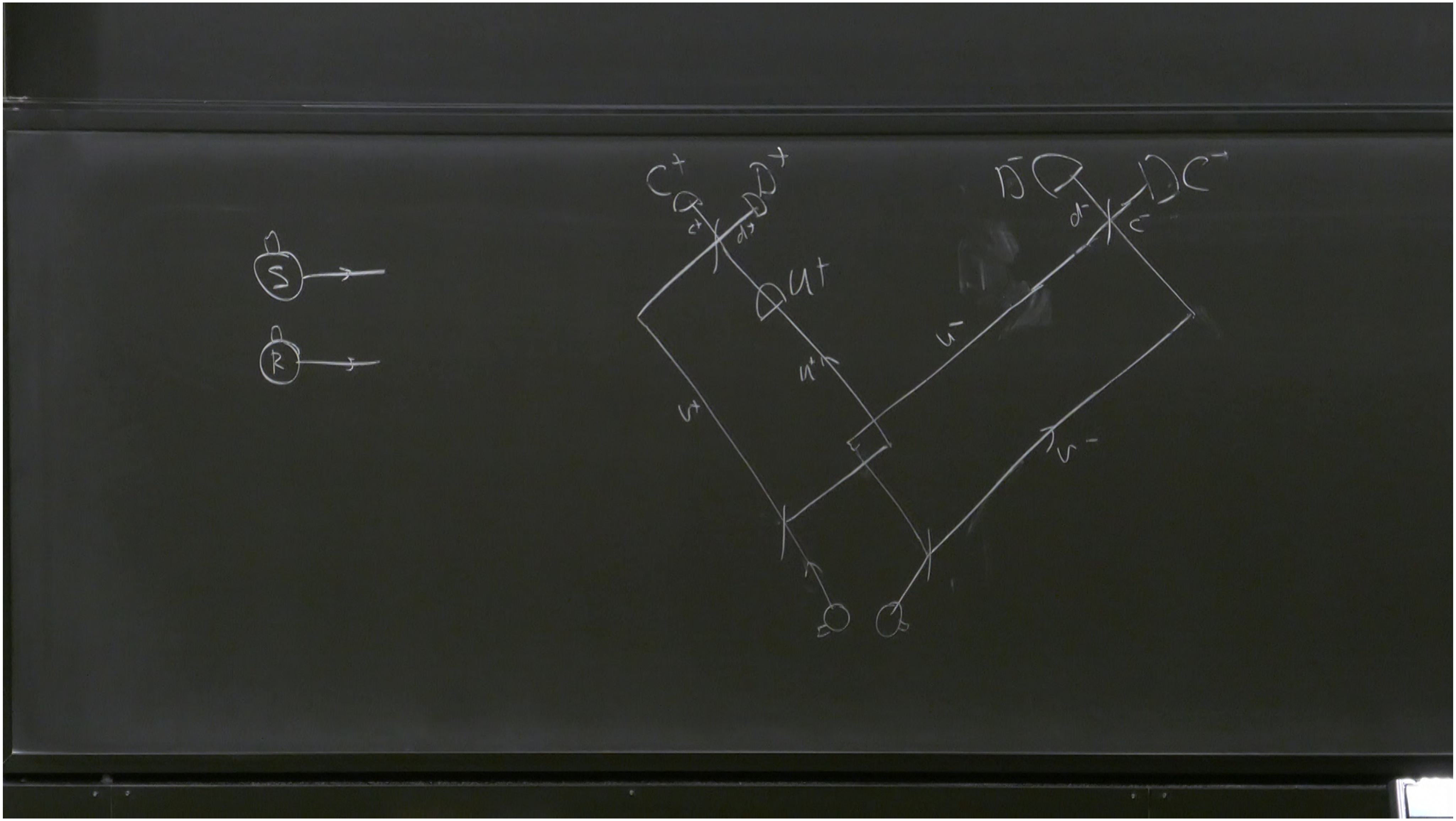

S
R
C+
D+
D-
C-
u+
u-


S
R
C^+
D^+
D^-
C^-
U^-
u^+
u^-


S
R
C^+
D^+
c^+
d^+
u^+
D^-
C^-
d^-
c^-
u^-

$$D^+ \Rightarrow U^-$$

$$U^+ \Leftarrow D^-$$

$D^+ \pitchfork D^-$ happens sometimes

$D^+ \Rightarrow U^-$

$U^+ \Leftarrow D^-$

$D^+ \propto D^-$ happens sometimes.

$D^+ \Rightarrow U^-$

$U^+ \Leftarrow D^-$

$U^+ \propto U^-$ never happens.

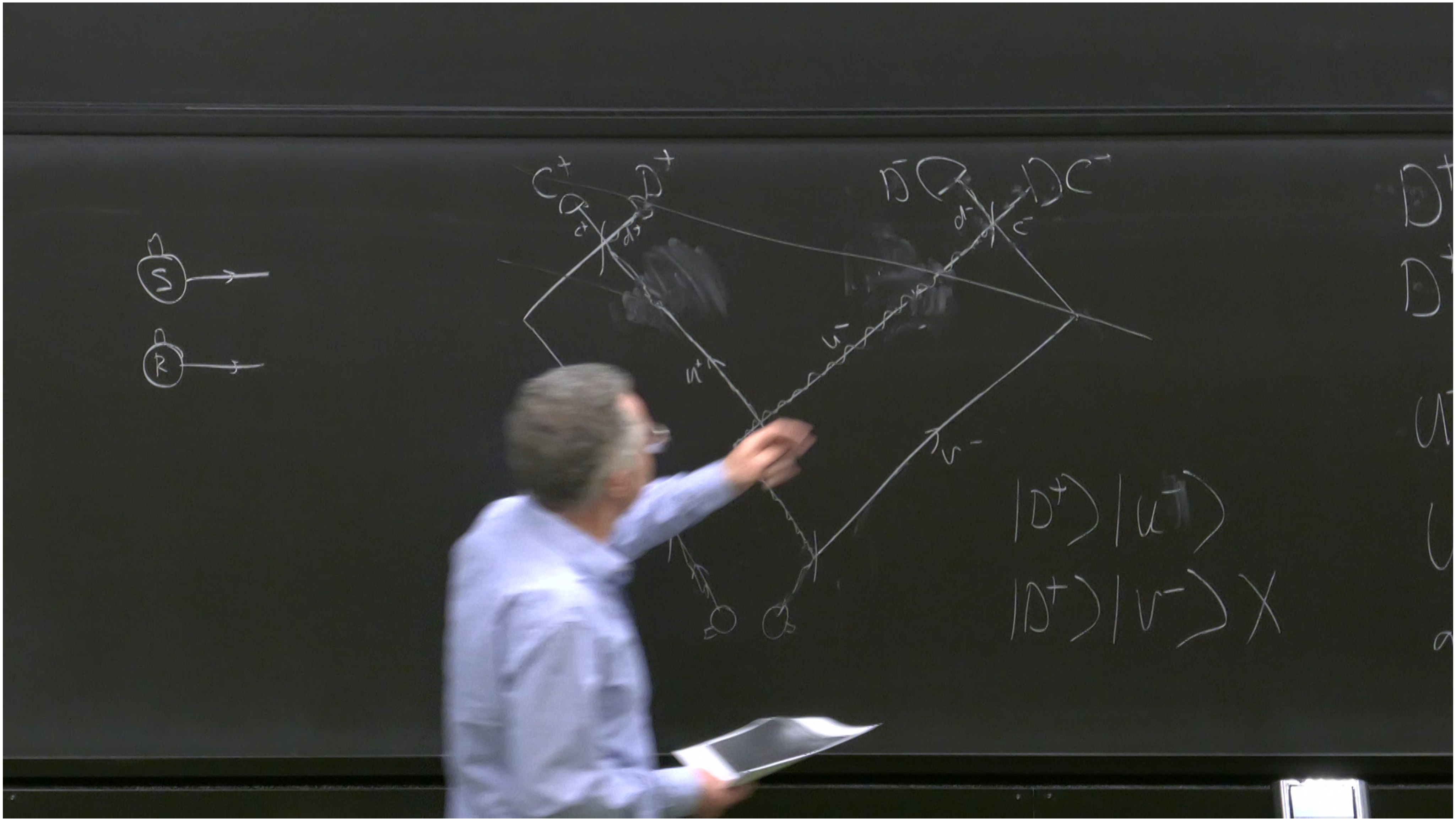
$D^+ \not\subset D^-$ happens sometimes.

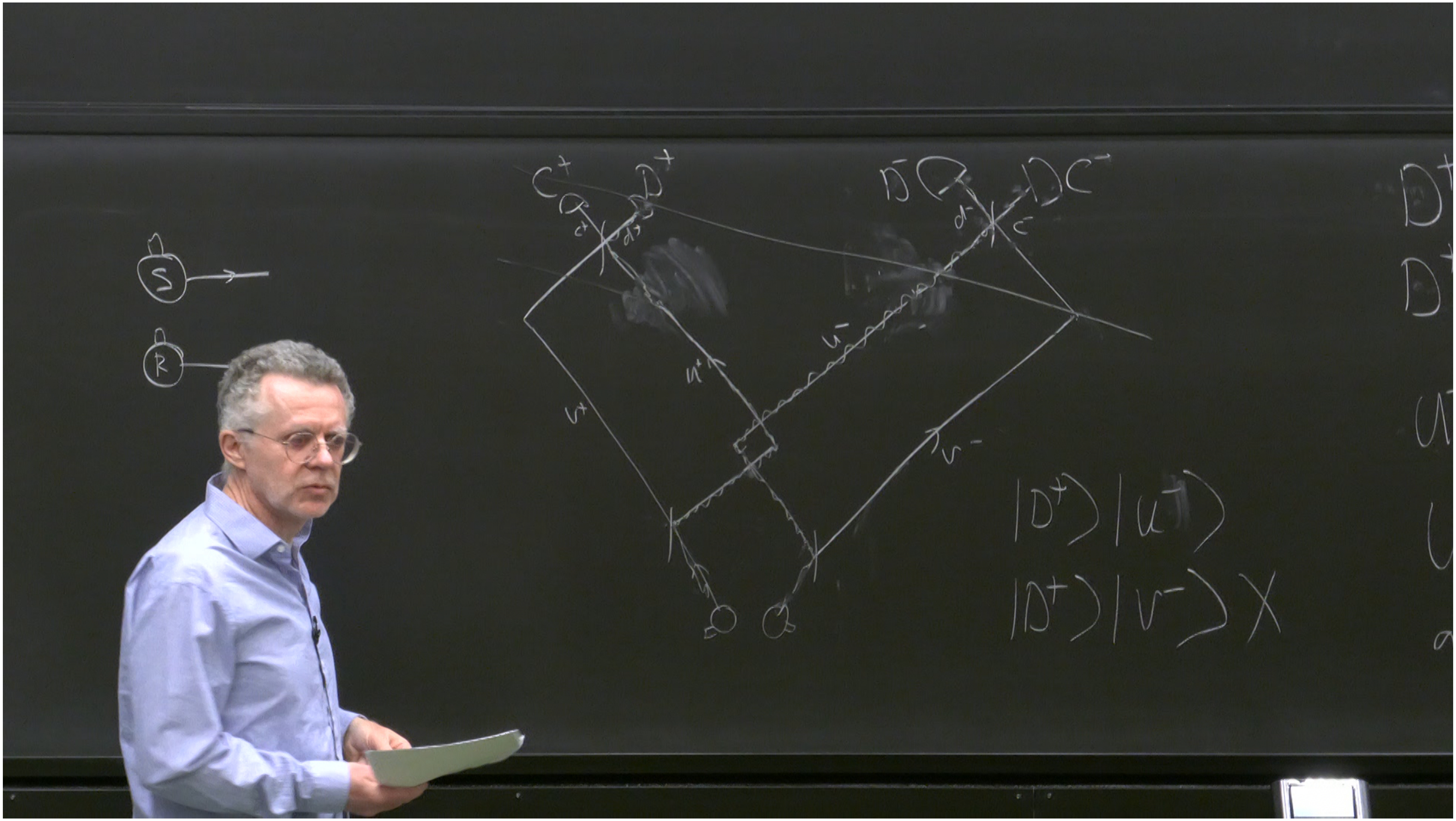
$D^+ \Rightarrow U^-$

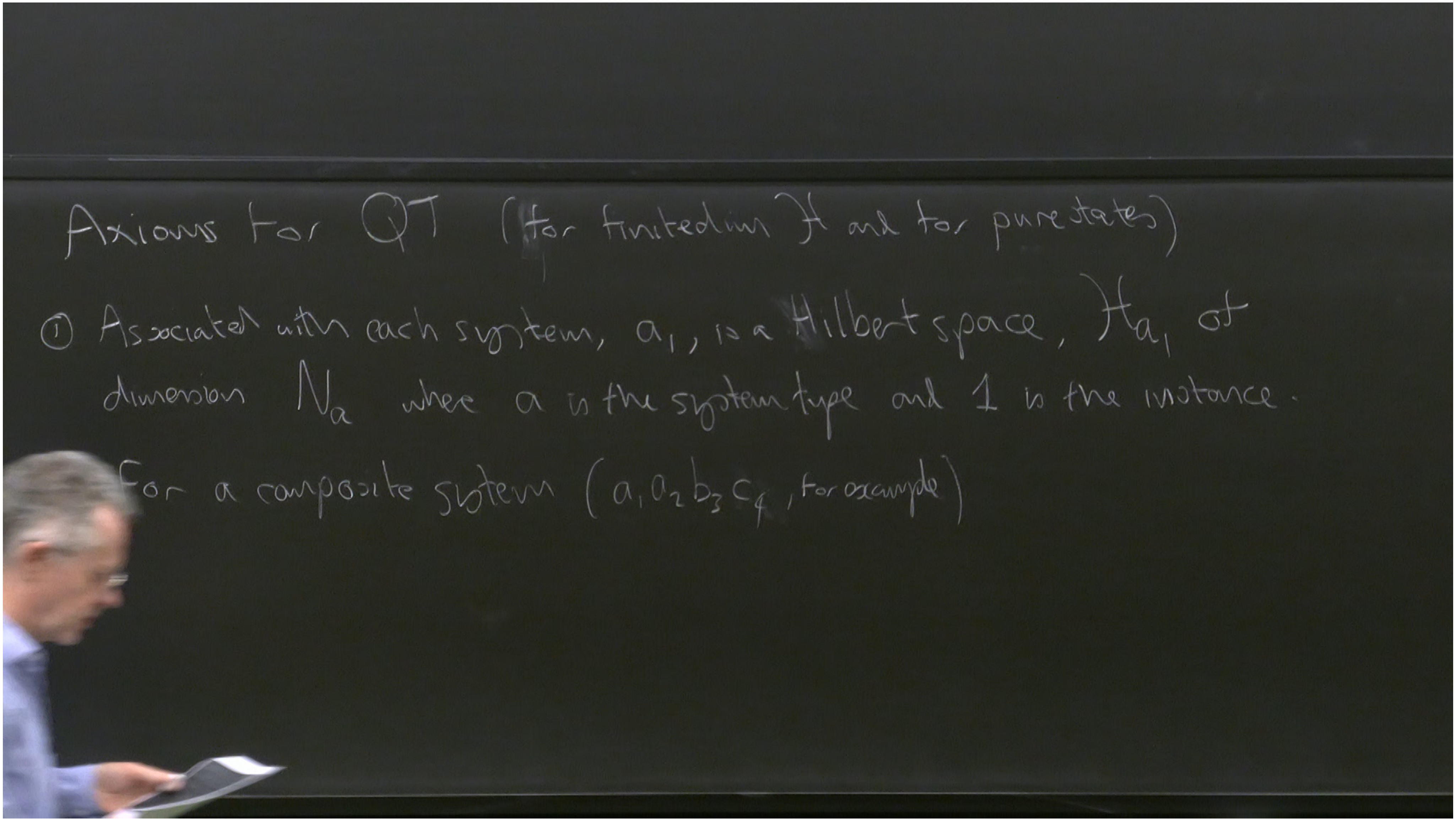
$U^+ \Leftarrow D^-$

$U^+ \not\subset U^-$ never happens.

apparent contradiction.


C^+
D^+
D^-
D
C^-
S
R
u^+
u^-
v^-
$|D^+\rangle|u^-\rangle$
$|D^+\rangle|v^-\rangle$ X


C+
D+
D−
C−
S
R
|D+⟩|u−⟩
|D+⟩|v−⟩ X


Axioms for QT (for finite dim $\mathcal{H}$ and for pure states)
① Associated with each system, a_1, is a Hilbert space, $\mathcal{H}_{a_1}$ of
dimension N_a where a is the system type and 1 is the instance.
For a composite system ($a_1 a_2 b_3 c_4$, for example)

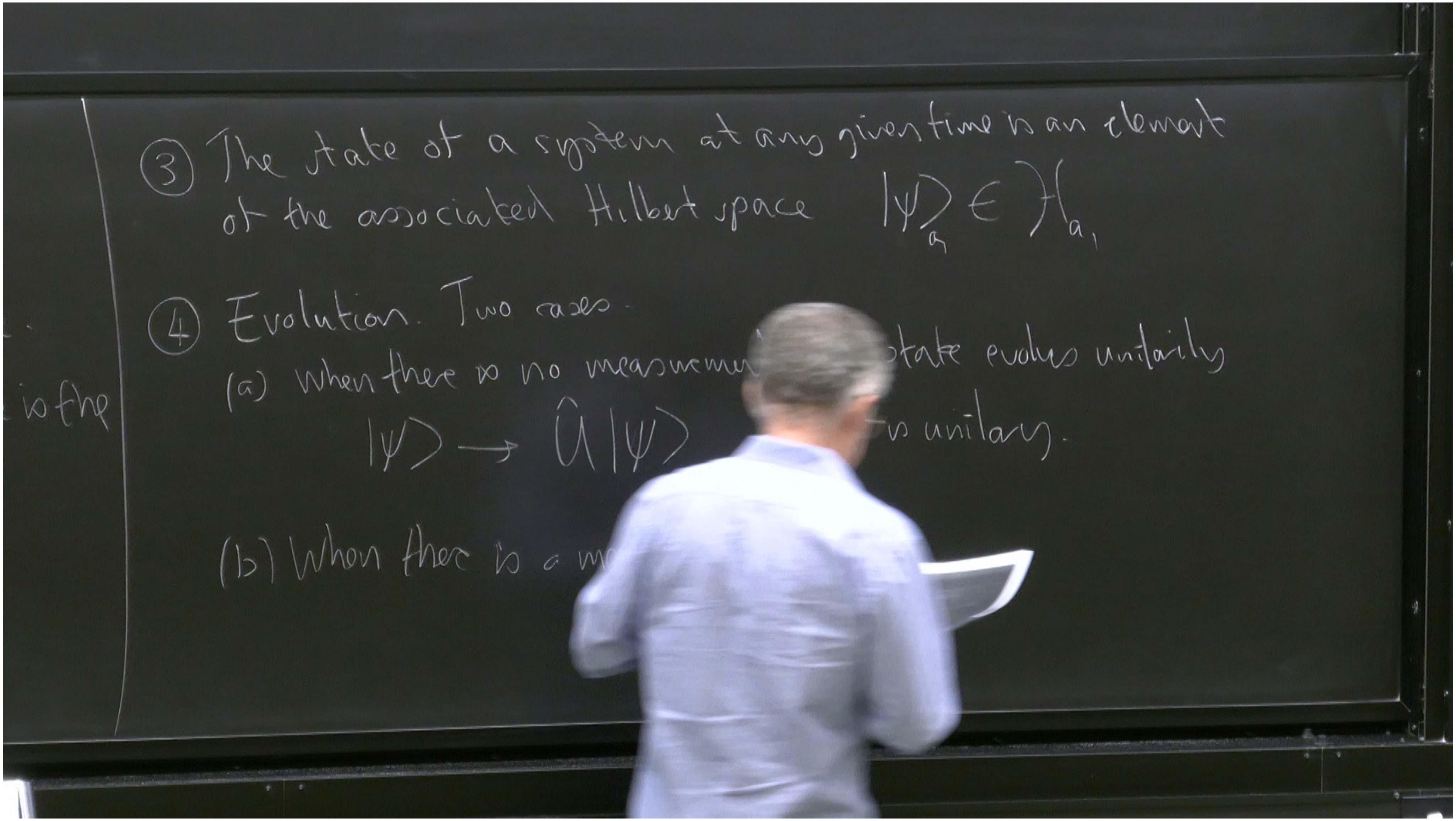
Axioms for QT (for finite dim $\mathcal{H}$ and for pure states)

① Associated with each system, a_1, is a Hilbert space, $\mathcal{H}_{a_1}$ of dimension N_a where a is the system type and 1 is the instance.

② For a composite system ($a_1 a_2 b_3 c_4$, for example) the Hilbert space is the tensor product of the Hilbert spaces of the components ($\mathcal{H}_{a_1} \otimes \mathcal{H}_{a_2} \otimes \mathcal{H}_{b_3} \otimes \mathcal{H}_{c_4}$ in our example).

③ The state of a system at any given time is an element of the associated Hilbert space $|\psi\rangle_{a_1} \in \mathcal{H}_{a_1}$

is the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④ Evolution. Two cases.
(a) When there is no measurement
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$|\psi\rangle \rightarrow \hat{U}|\psi\rangle$
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(b) When there is a m

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④ Evolution. Two cases.

(a) When there is no measurement the state evolves unitarily

$$|\psi\rangle \rightarrow \hat{U}|\psi\rangle \qquad \hat{U} \text{ is unitary.}$$

(b) When there is a measurement the state is projected with the projector associated with the measurement outcome we see

$$|\psi\rangle \rightarrow \hat{P}|\psi\rangle \qquad \hat{P} \text{ is a projector.}$$

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⑤ The probability of a given measurement outcome is given by the square modulus of the amplitude in front of the state after projection

$$\text{prob} = \left(\langle\psi|\hat{P} \ \hat{P}|\psi\rangle\right) = \langle\psi|\hat{P}|\psi\rangle$$

The Born rule

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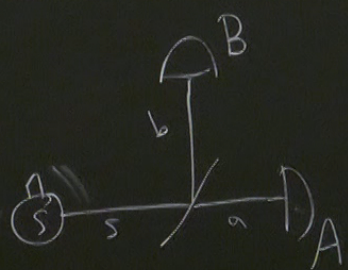
where $\langle\psi|\psi\rangle = 1.$

$$\frac{\hat{P}|\psi\rangle}{\langle\psi|P|\psi\rangle}$$

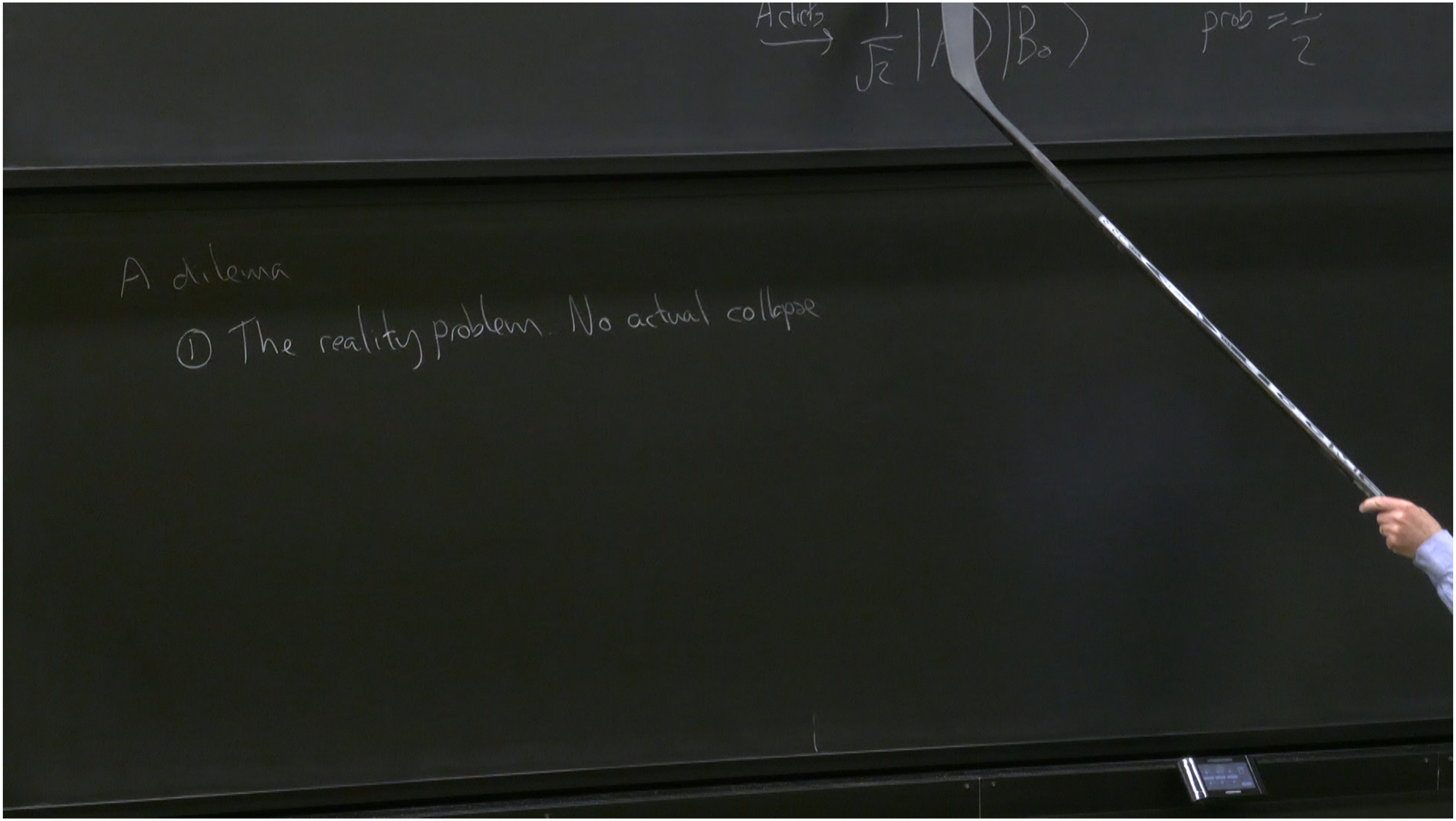
The measurement problem



$$|s\rangle|A_0\rangle|B_0\rangle \rightarrow \left(\frac{1}{\sqrt{2}}|a\rangle + \frac{i}{\sqrt{2}}|b\rangle\right)|A_0\rangle|B_0\rangle$$

$$\rightarrow \frac{1}{\sqrt{2}}|A\rangle|B_0\rangle + \frac{i}{\sqrt{2}}|A_0\rangle|B\rangle$$

$$\xrightarrow{\text{A clicks}} \frac{1}{\sqrt{2}}|A\rangle|B_0\rangle \qquad \text{prob} = \frac{1}{2}$$


A clicks
A dilema
① The reality problem. No actual collapse

$$\xrightarrow{\text{A clicks}} \frac{1}{\sqrt{2}}|A\rangle|B_0\rangle \qquad \text{prob} = \frac{1}{2}$$

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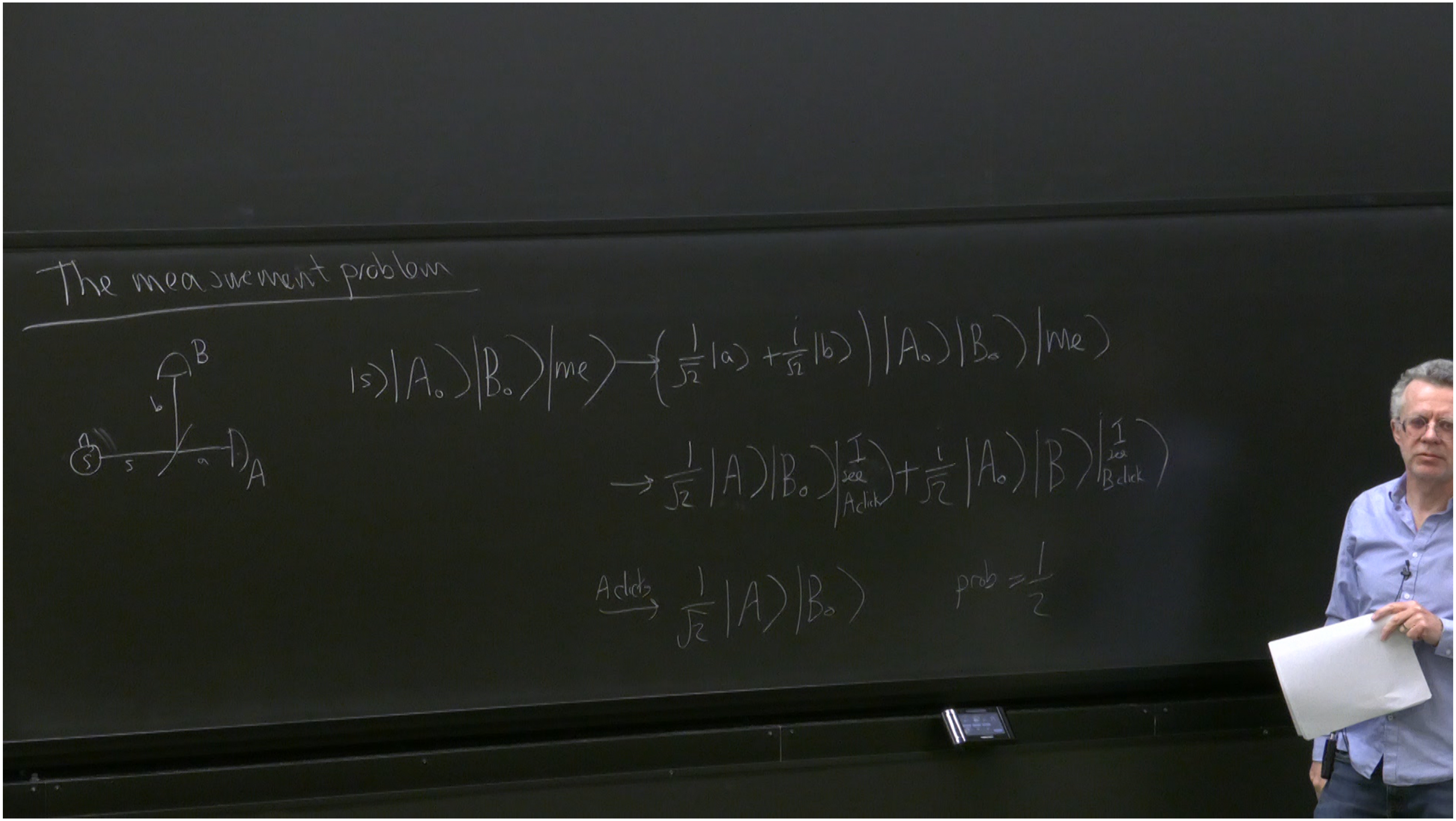
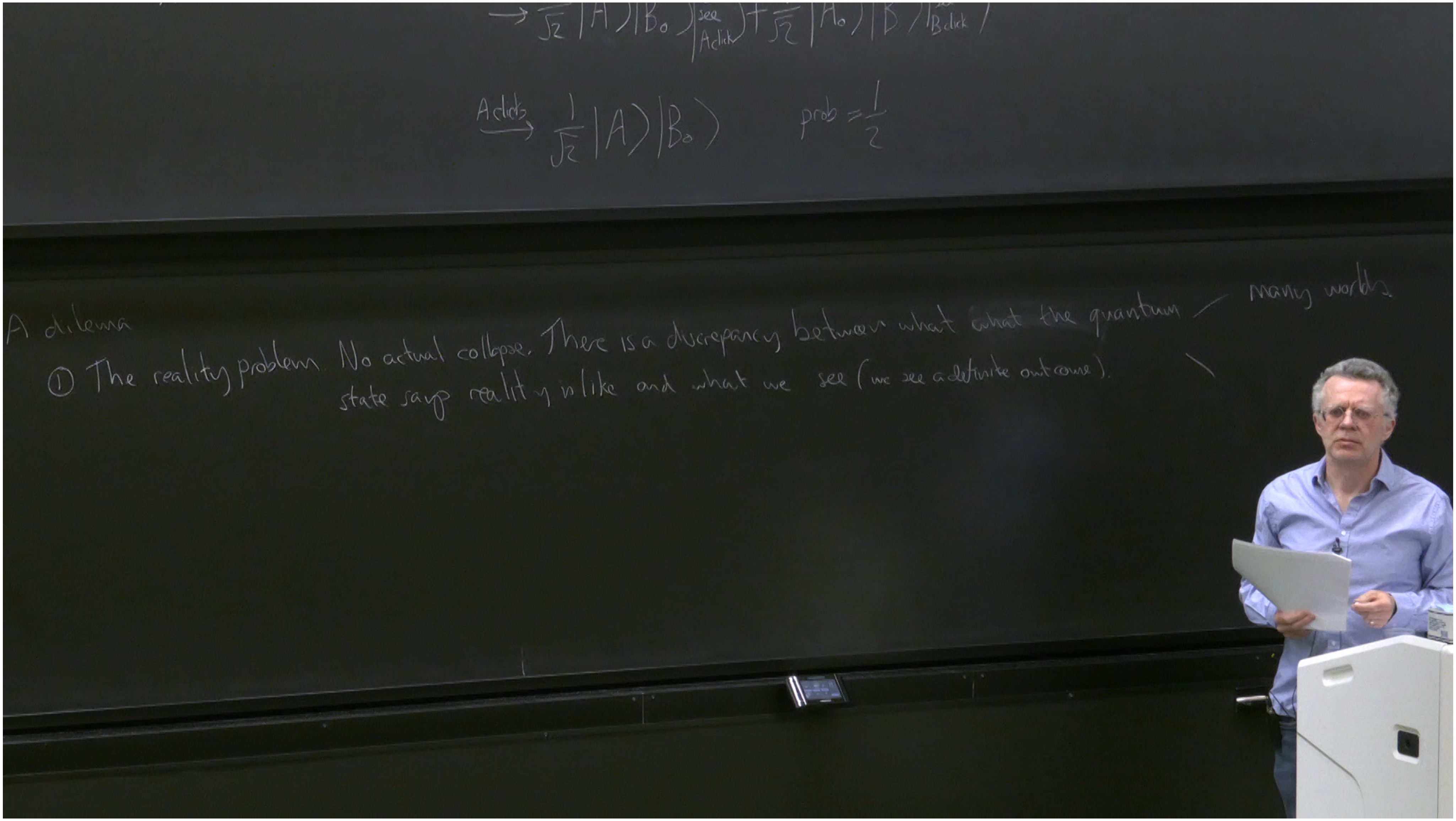
① The reality problem. No actual collapse. There is a discrepancy between what ~~what~~ the quantum state says reality is like and what we see (we see a definite outcome).


The measurement problem
B
b
s
a
A
|s⟩|A₀⟩|B₀⟩|me⟩ → (1/√2 |a⟩ + i/√2 |b⟩) |A₀⟩|B₀⟩|me⟩
→ 1/√2 |A⟩|B₀⟩|I see A click⟩ + i/√2 |A₀⟩|B⟩|I see B click⟩
A clicks → 1/√2 |A⟩|B₀⟩
prob = 1/2



A clicks → 1/√2 |A)|B₀)   prob = 1/2
A dilema
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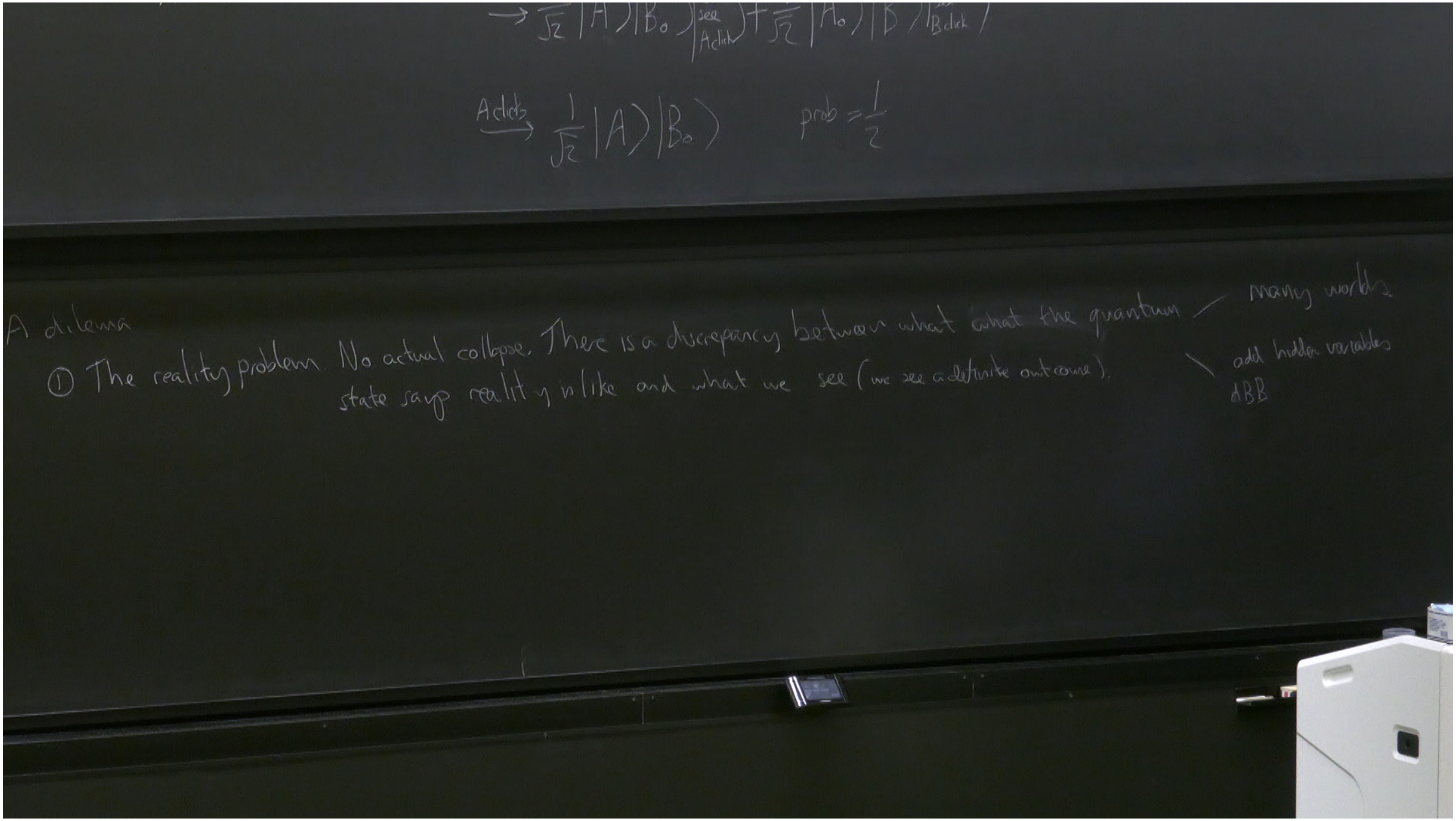
many worlds



$\rightarrow \frac{1}{\sqrt{2}}|A\rangle|B_0\rangle|\text{see A click}\rangle + \frac{1}{\sqrt{2}}|A_0\rangle|B\rangle|\text{B click}\rangle$
$\xrightarrow{\text{A clicks}} \frac{1}{\sqrt{2}}|A\rangle|B_0\rangle$
prob $= \frac{1}{2}$
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many worlds
add hidden variables
dBB

A dilema

1. The reality problem. No actual collapse. There is a discrepancy betwe state says reality is like and what we see

2. The collapse problem. What qualifies as measurement?

A dilema

① The reality problem. No actual collapse. There is a discrepancy betw
state says reality is like and what we see

② The collapse problem. What qualifies as measurement?

(i) Easy problem. What basis is (our sensation of) definite outcomes wrt?

why not $\frac{1}{\sqrt{2}}\left(\left|\begin{matrix}I\\ \text{see}\\ \text{A click}\end{matrix}\right\rangle \pm \left|\begin{matrix}I\\ \text{see}\\ \text{B click}\end{matrix}\right\rangle\right)$ Use decoherence theory.

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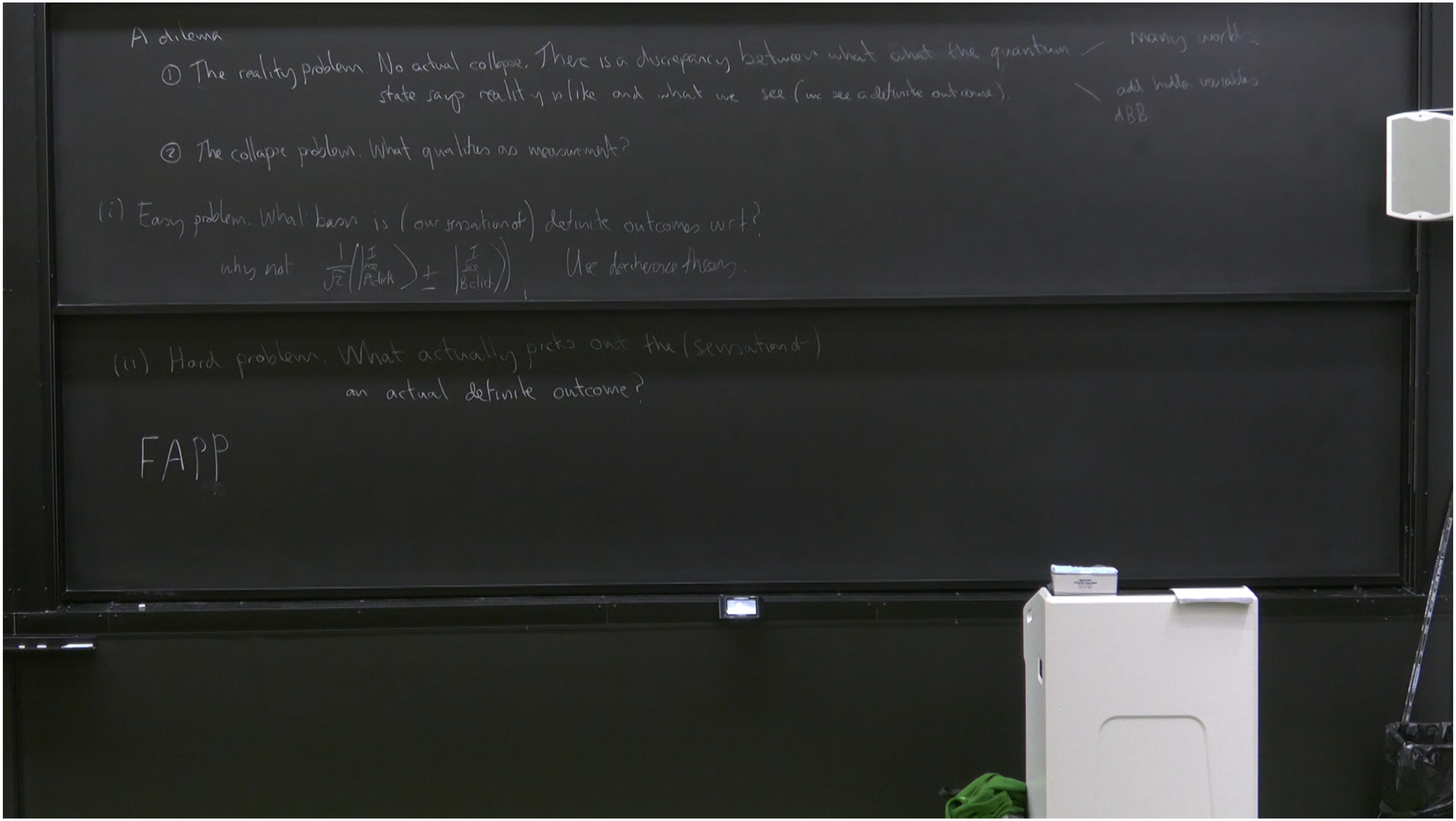
(ii) Hard problem. What actually picks out the (sensation of) an actual definite outcome?



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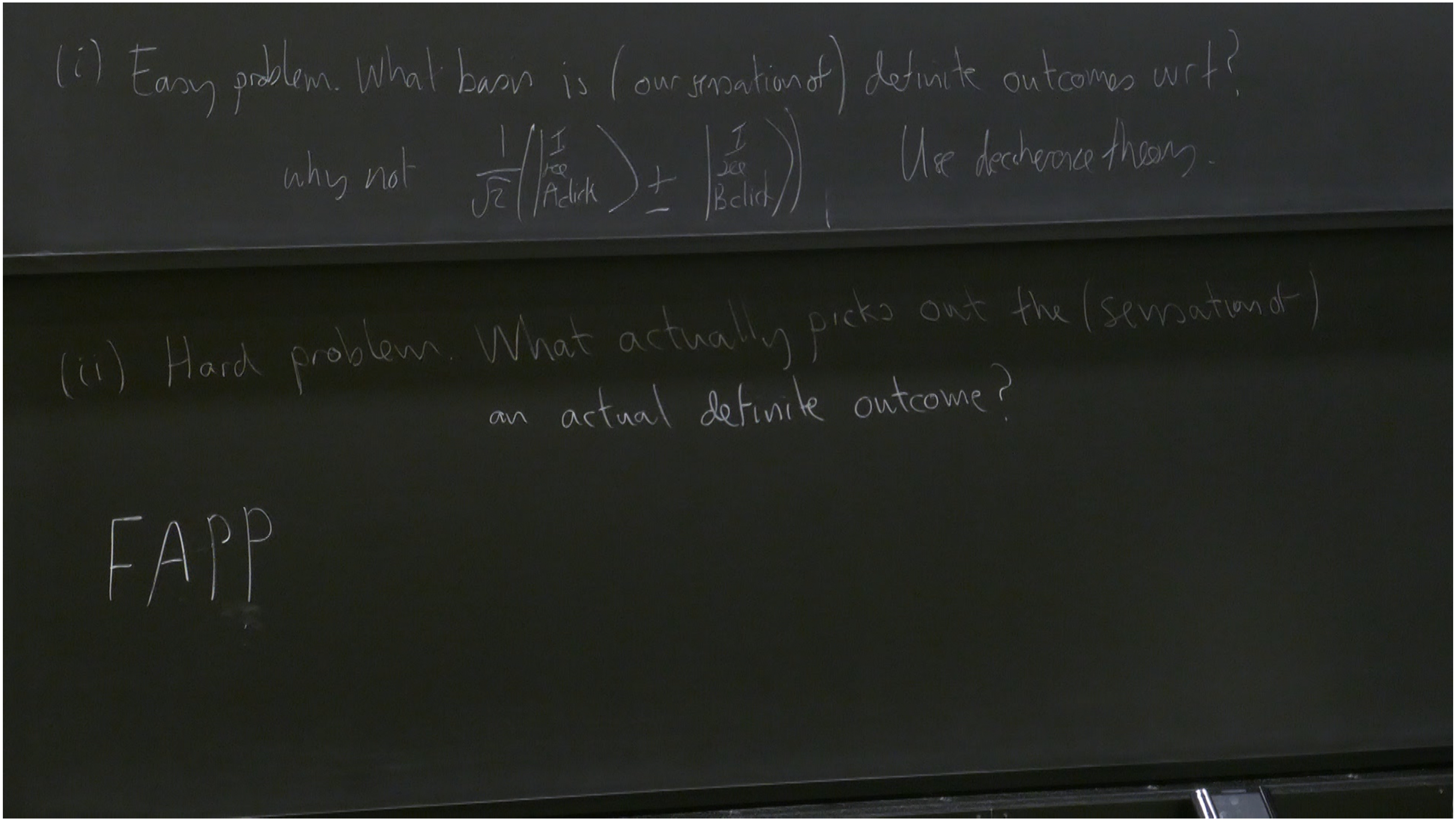
FAPP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