Title: Quantum Foundations Lecture - 230120

Speakers: Lucien Hardy

Collection: Quantum Foundations (2022/2023)

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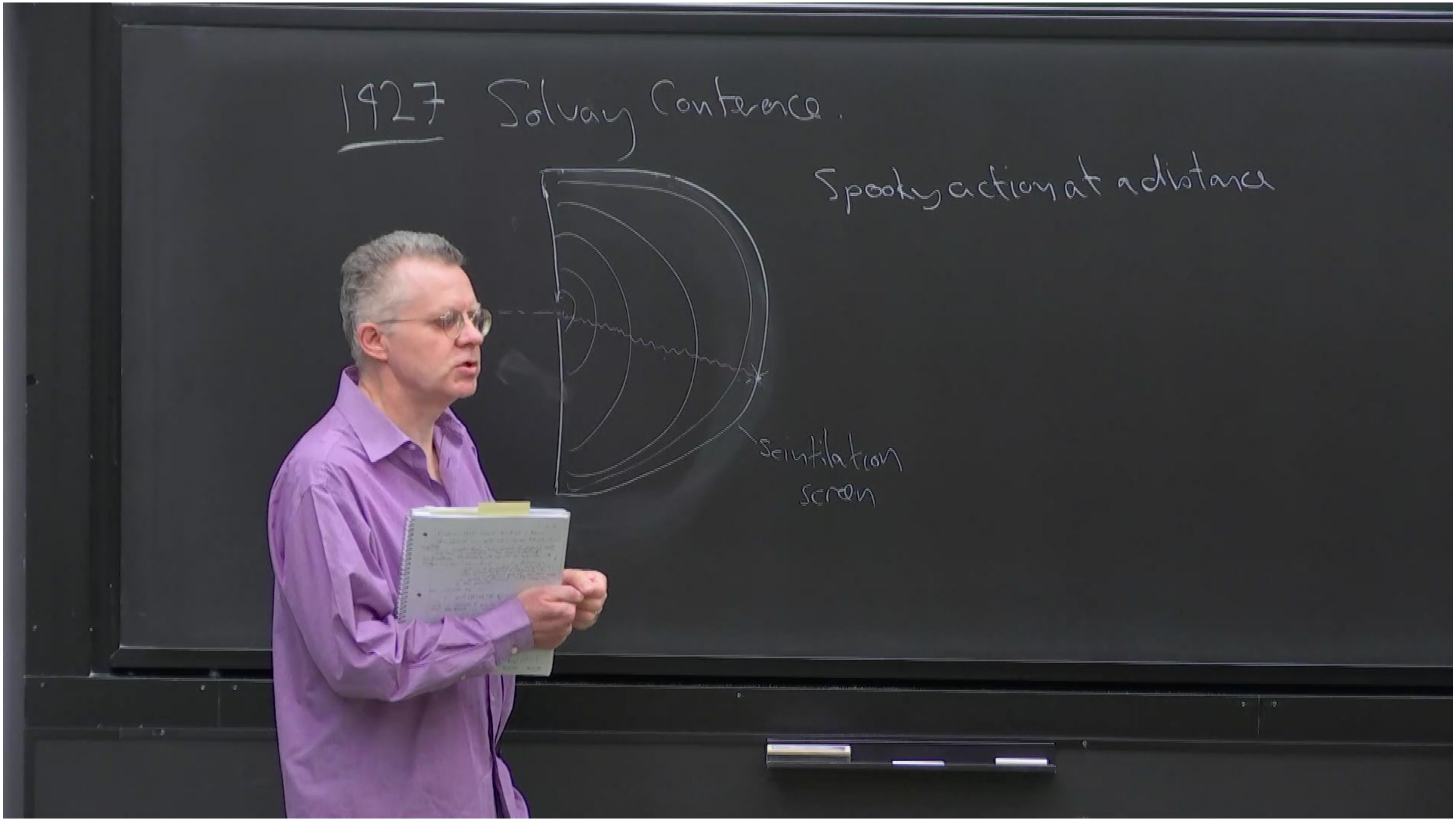
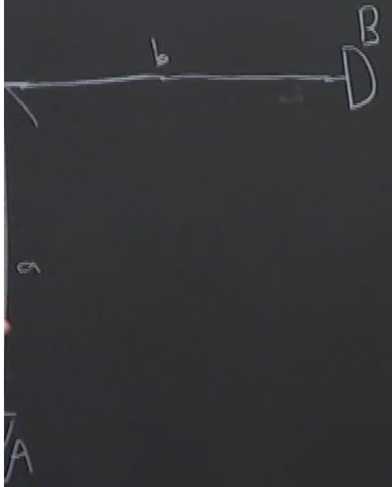
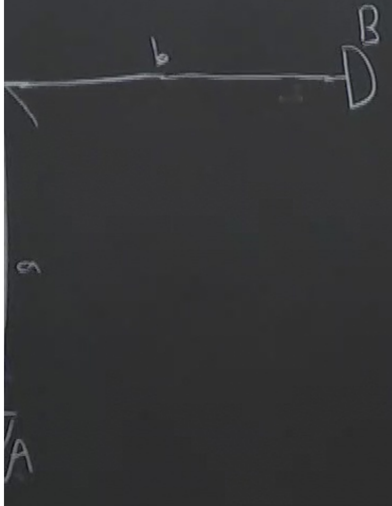

1927 Solvay Conference.
Spooky action at a distance
Scintilation
screen



Take def^{n}s from EPR paper

<u>Completeness</u> In a complete theory "every element of physical reality (epr) must have a counterpart in the physical theory".

ψ-completeness



Take def^{n}s from EPR paper

<u>Completeness</u> In a complete theory "every element of physical reality (epr) must have a counterpart in the physical theory".

ψ-completeness All epr's follow from the state vector

$[A=\alpha]_a$ is an epr iff $\langle \psi | \hat{P}_{(A=\alpha)_a} | \psi \rangle = 1$

Sufficient criterion for the existence of an epr

"If, without in any way disturbing a system, we can predict with certainty (i.e with probability equal to unity)

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"If, without in any way disturbing a system, we can predict with certainty (i.e with probability equal to unity) the value of a physical quantity, then there exists an epr corresponding to this quantity."

$\Rightarrow$ If $\mathrm{prob}\left((A=\alpha)_a \,\middle|\, (B=1)_b \right) = 1$ and if measurement B does not distur[b] system a then $\exists$ an epr $[A=\alpha]_a$

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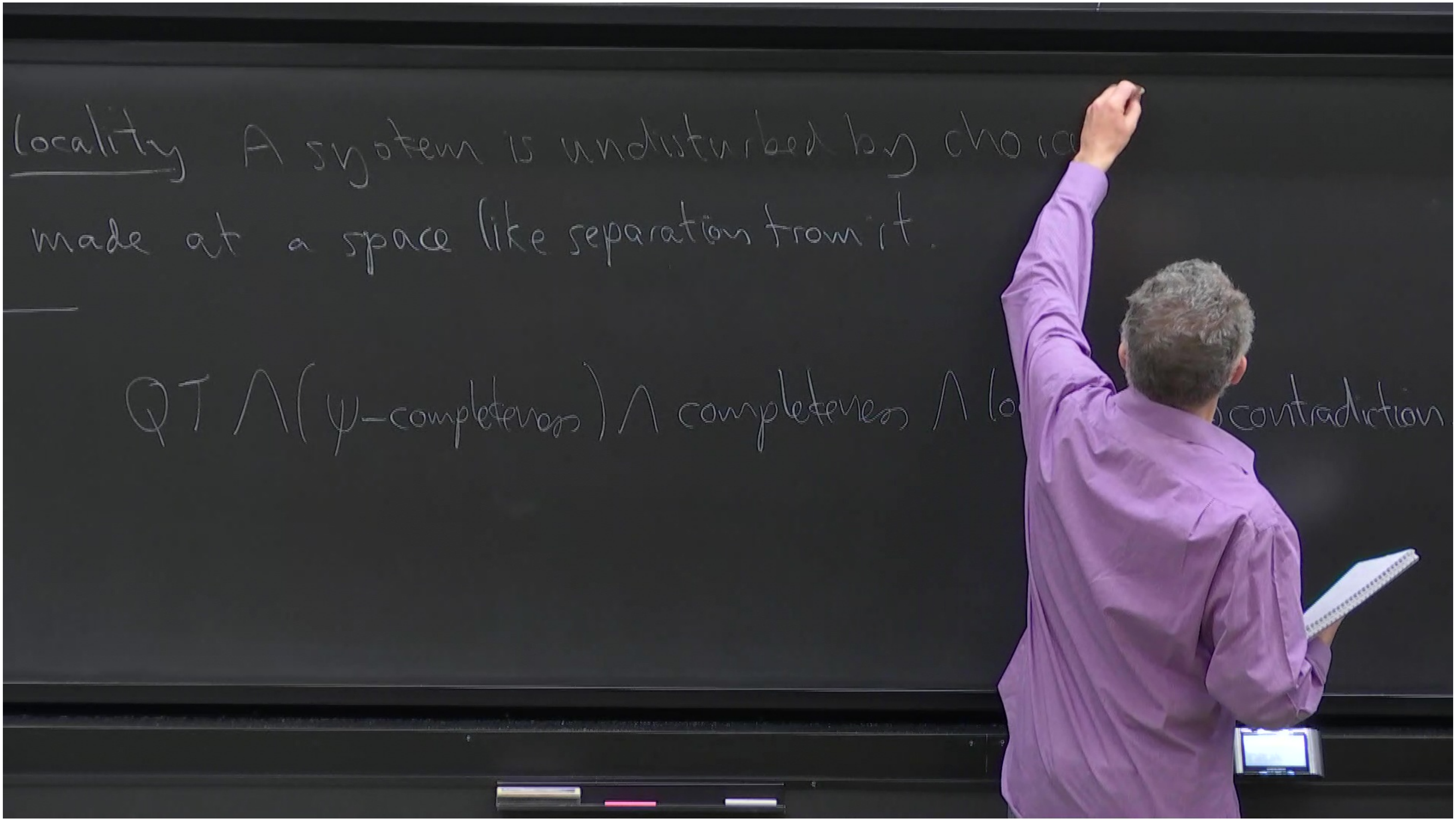
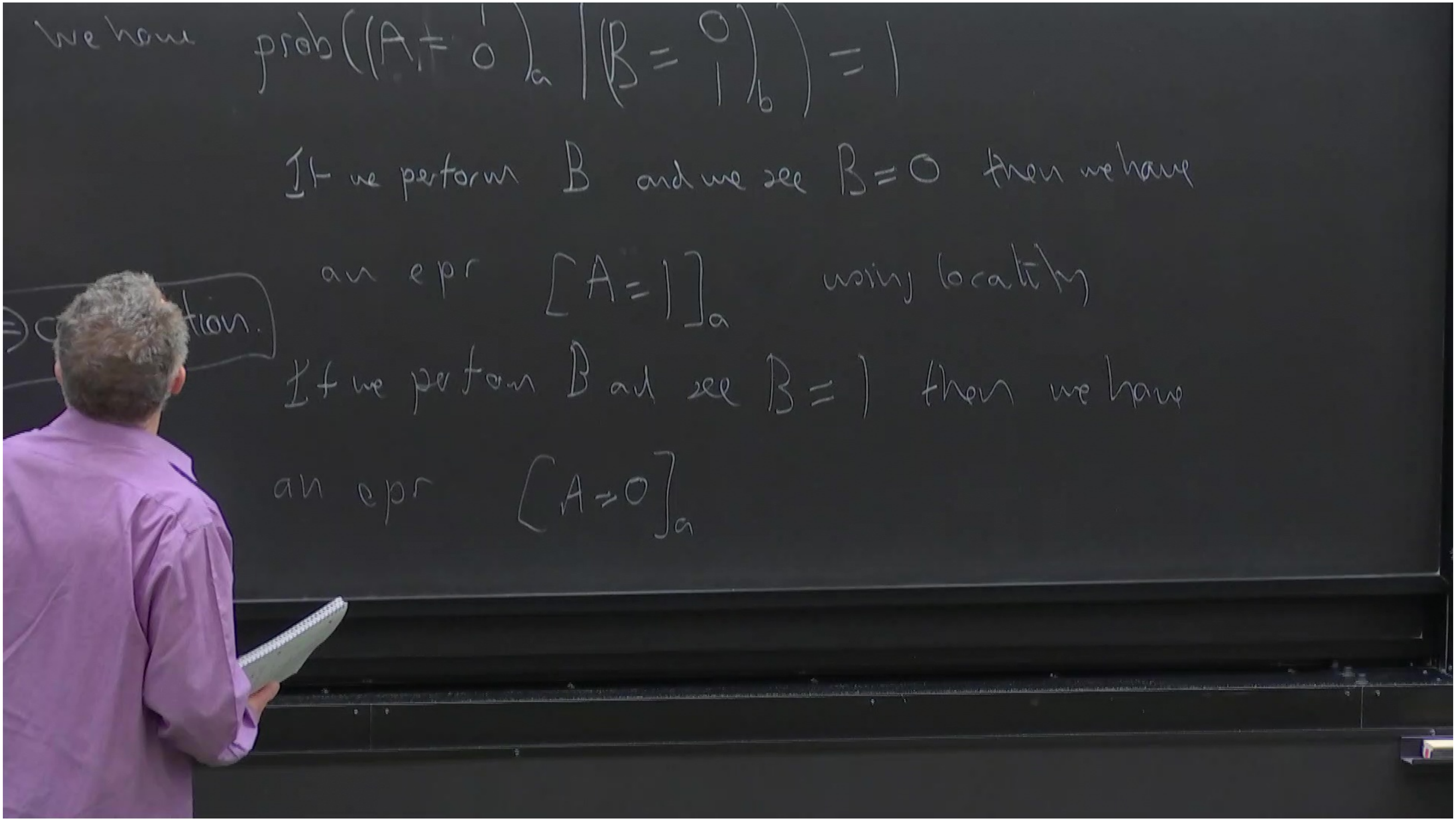
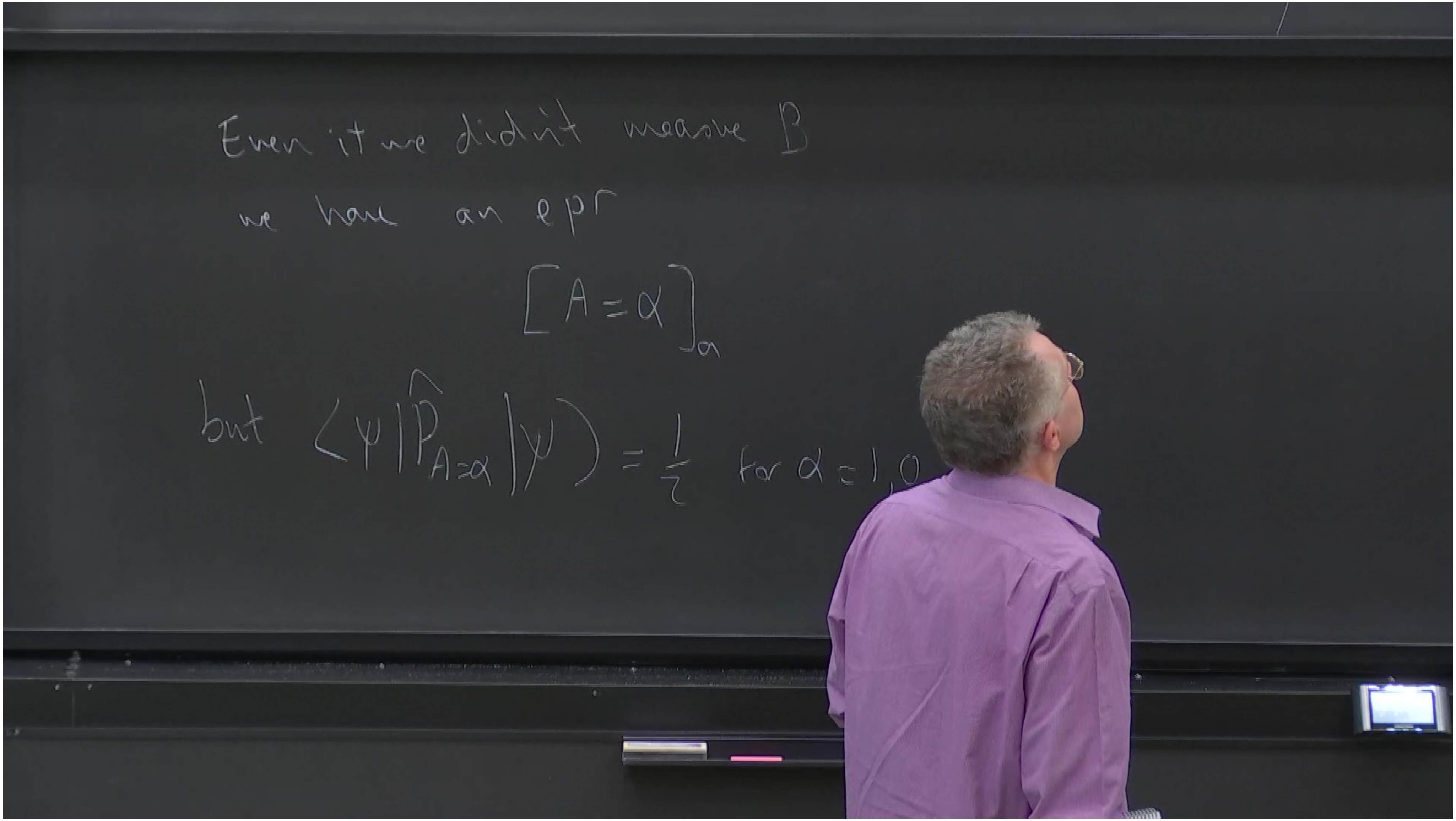
$\Rightarrow$ If $\text{prob}\left((A=\alpha)_a \,\middle|\, (B=1)_b \right) = 1$ and if measurement B does not distur[b] system a then $\exists$ an epr $[A=\alpha]_a$

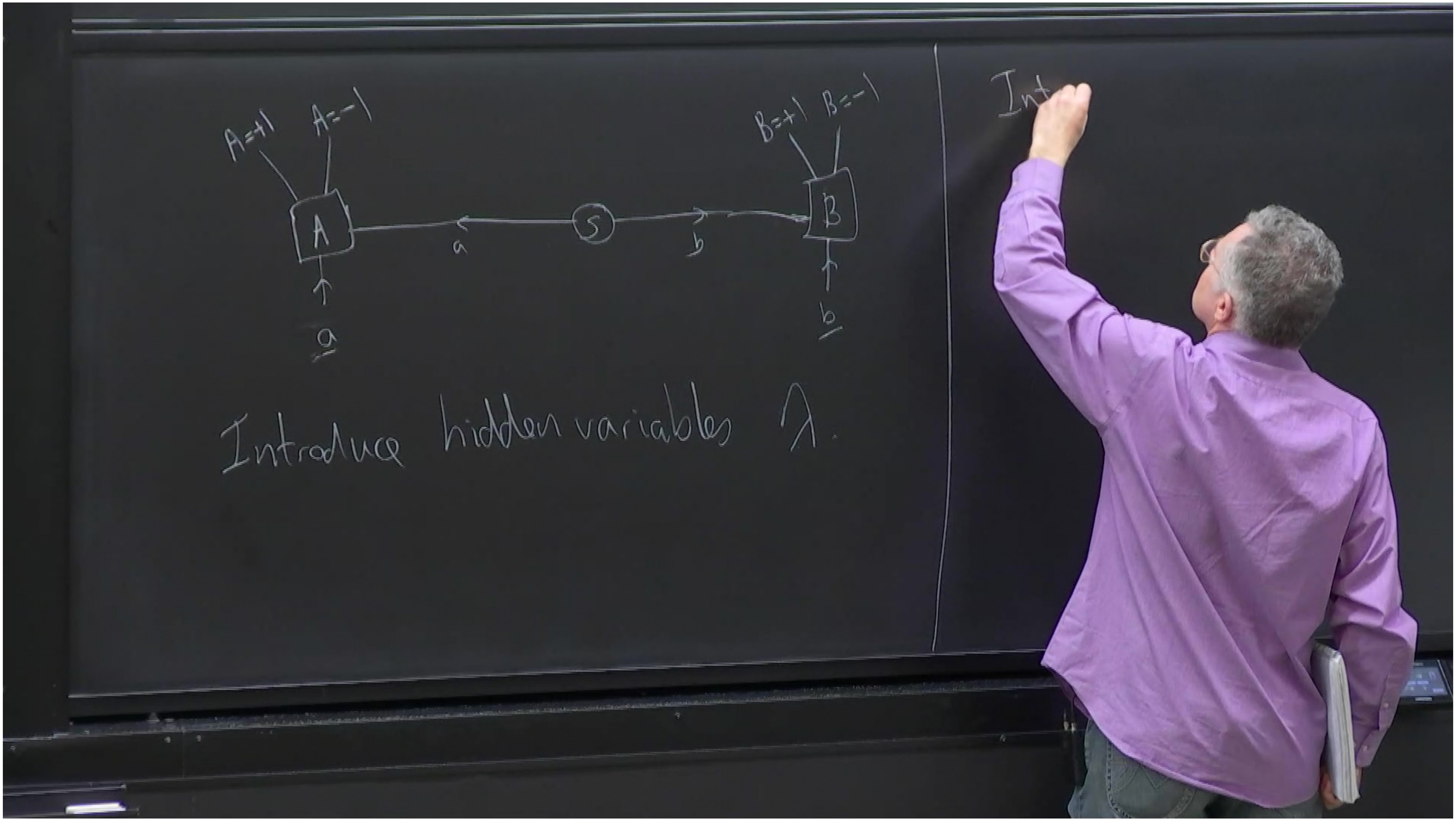

locality A system is undisturbed by choic
made at a space like separation from it.
QT ∧ (ψ-completeness) ∧ completeness ∧ lo
contradiction.

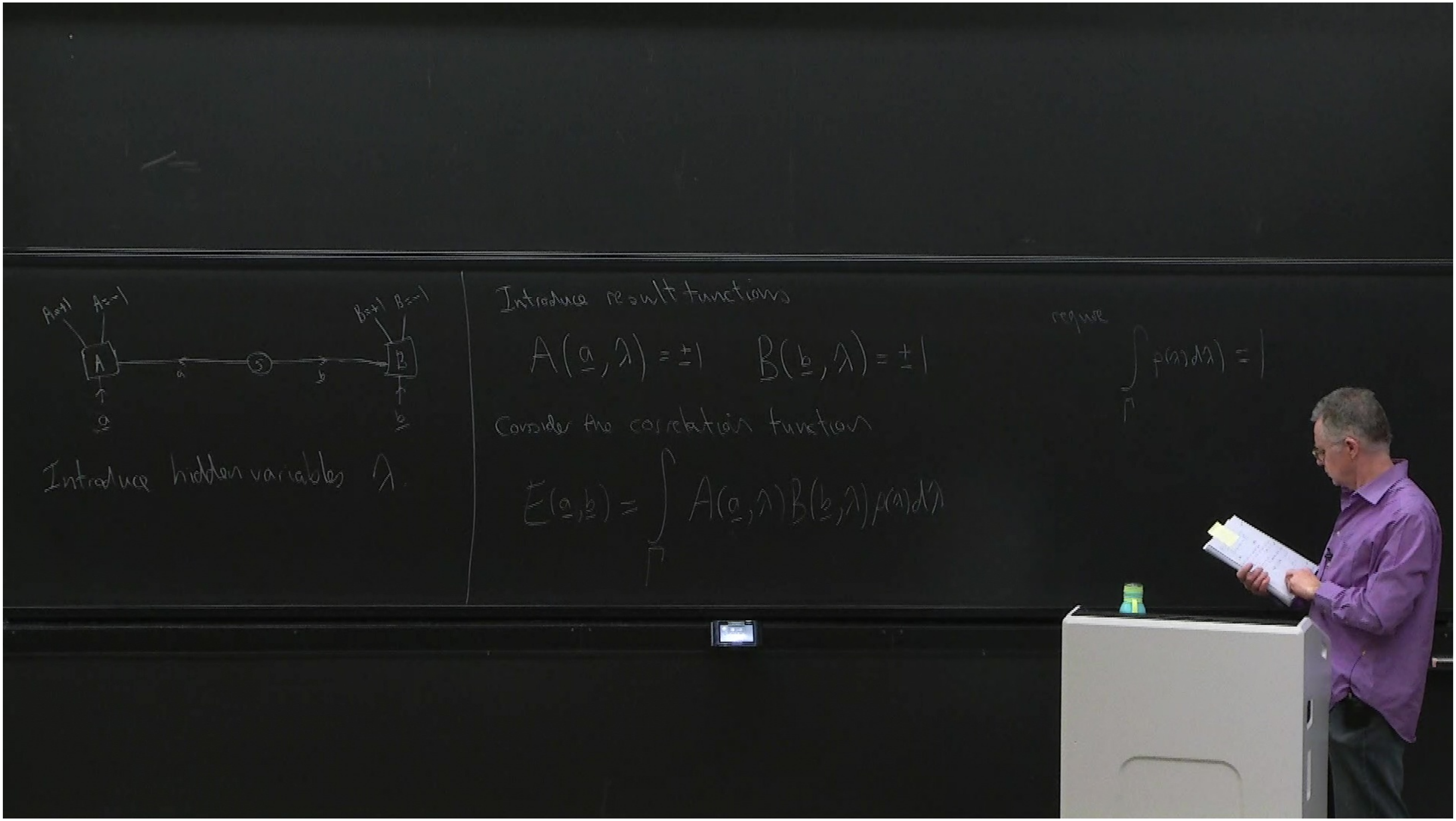

We have $\mathrm{prob}\left(\begin{pmatrix}A = & 1 \\ & 0\end{pmatrix}_a \middle| \begin{pmatrix}B = & 0 \\ & 1\end{pmatrix}_b\right) = 1$
If we perform B and we see B = 0 then we have
an epr $[A=1]_a$ using locality
If we perform B and see B = 1 then we have
an epr $[A=0]_a$
tion.

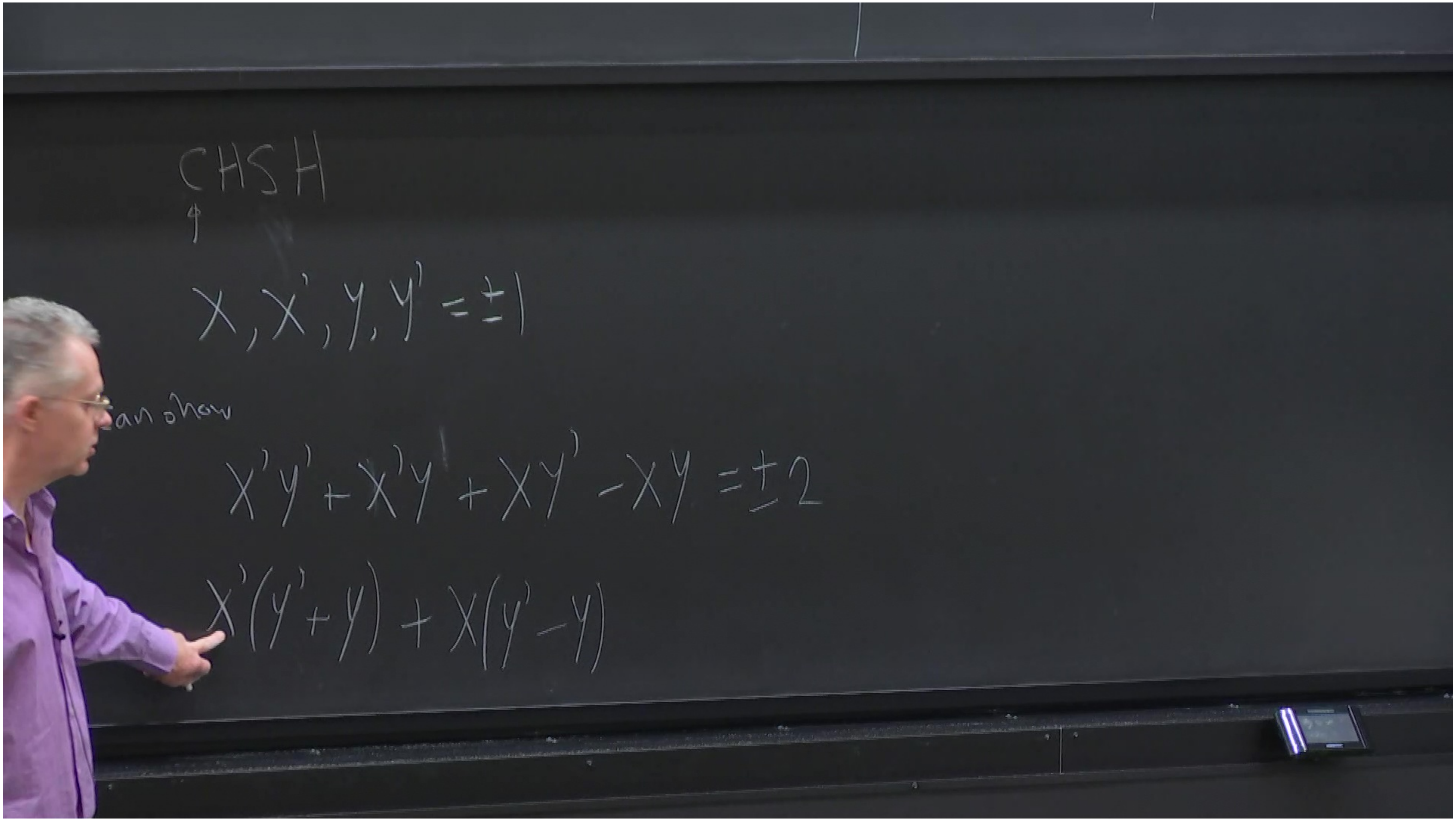

Even if we didn't measure B
we have an epr
$[A = \alpha]_\alpha$
but $\langle \psi | \hat{P}_{A=\alpha} | \psi \rangle = \frac{1}{2}$ for $\alpha = 1, 0$

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|+\rangle_a |-\rangle_b - |-\rangle_a |+\rangle_b\right)$$

$\alpha = 1, 0.$


A=+1
A=-1
A
a
S
b
B
B=+1
B=-1
Introduce hidden variables λ.
Int


A=+1 A=−1
B=+1 B=−1
A
S
B
Introduce hidden variables λ.
Introduce result functions
A(a, λ) = ±1   B(b, λ) = ±1
Consider the correlation function
E(a, b) = ∫_Γ A(a, λ) B(b, λ) ρ(λ) dλ
require
∫_Γ ρ(λ) dλ = 1


CHSH
X, X', Y, Y' = ±1
an show
X'Y' + X'Y + XY' − XY = ±2
X'(Y' + Y) + X(Y' − Y)

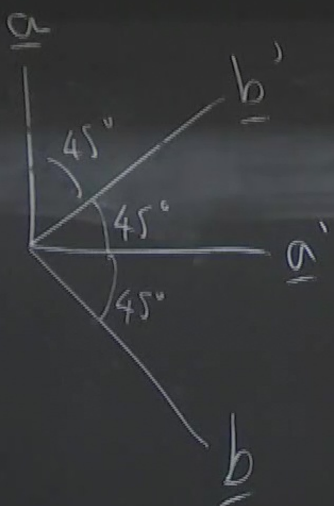
$$x = A(\underline{a},\lambda) \quad x' = A(\underline{a}',\lambda), \quad y = B(\underline{b},\lambda), \quad y' = B(\underline{b}',\lambda)$$

$$-2 \leq E(\underline{a}',\underline{b}') + E(a',b) + E(a,b') - E(a,b) \leq +2$$

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|+\rangle_a |-\rangle_b - |-\rangle_a |+\rangle_b\right)$$

At end A measure $\sigma_{\underline{a}}$ At end B meas $\sigma_{\underline{b}}$

$$E(\underline{a},\underline{b}) = \langle\psi|\sigma_{\underline{a}}\,\sigma_{\underline{b}}|\psi\rangle = -\underline{a}\cdot\underline{b}$$

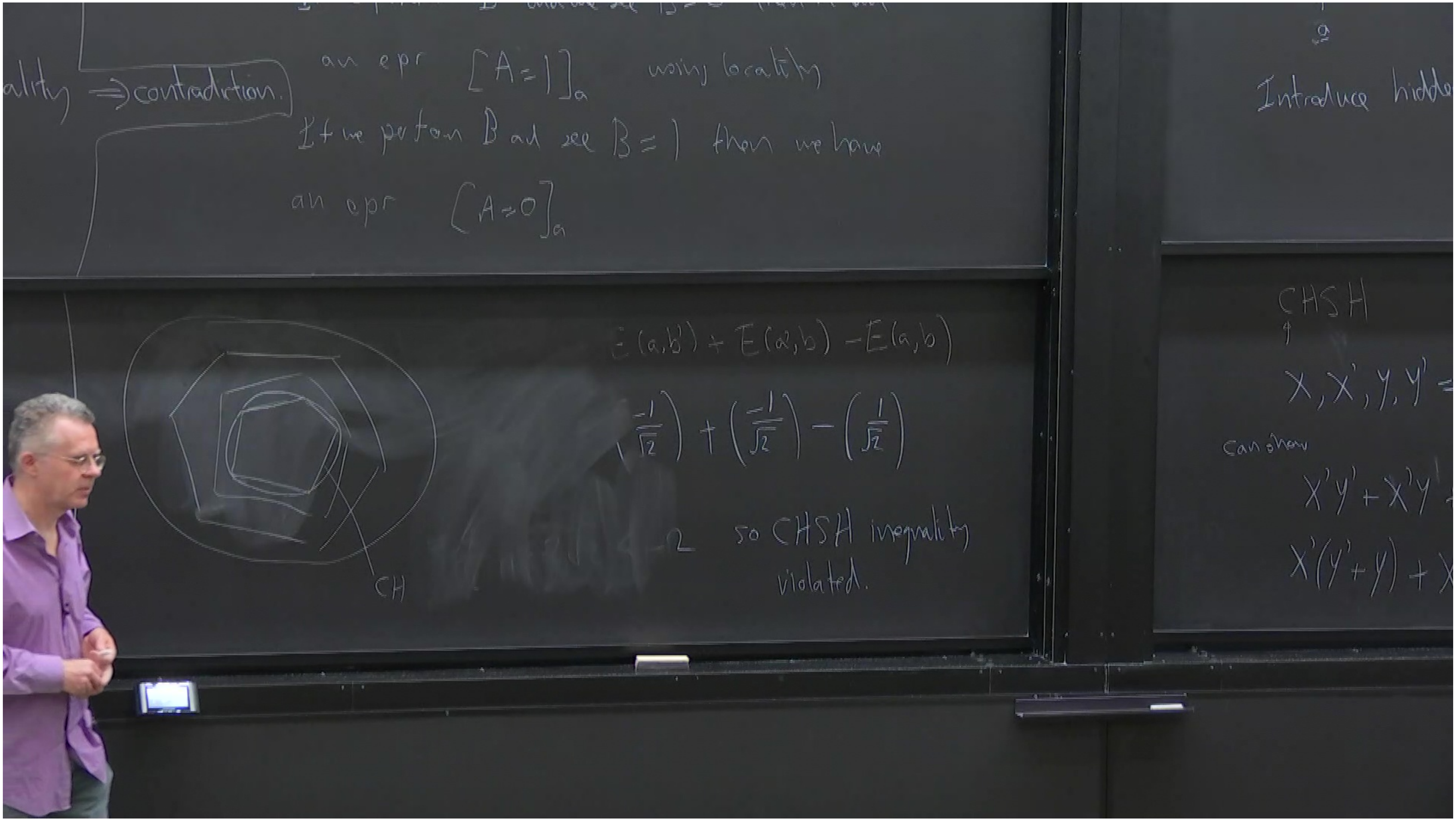


$$E(a',b') + E(a,b') + E(a',b) - E(a,b)$$

$$= \left(-\frac{1}{\sqrt{2}}\right) + \left(\frac{-1}{\sqrt{2}}\right) + \left(\frac{-1}{\sqrt{2}}\right) - \left(\frac{1}{\sqrt{2}}\right)$$

$$= \frac{-4}{\sqrt{2}} = -2\sqrt{2} < -2$$

so CHSH inequality violated.


ality ⇒ contradiction.
an epr [A=1]a using locality
If we perform B and see B=1 then we have
an epr [A=0]a
CH
E(a,b') + E(a',b) − E(a,b)
so CHSH inequality violated.
Introduce hidde
CHSH
X, X', Y, Y'
can show
X'Y' + X'Y
X'(Y'+Y) + X