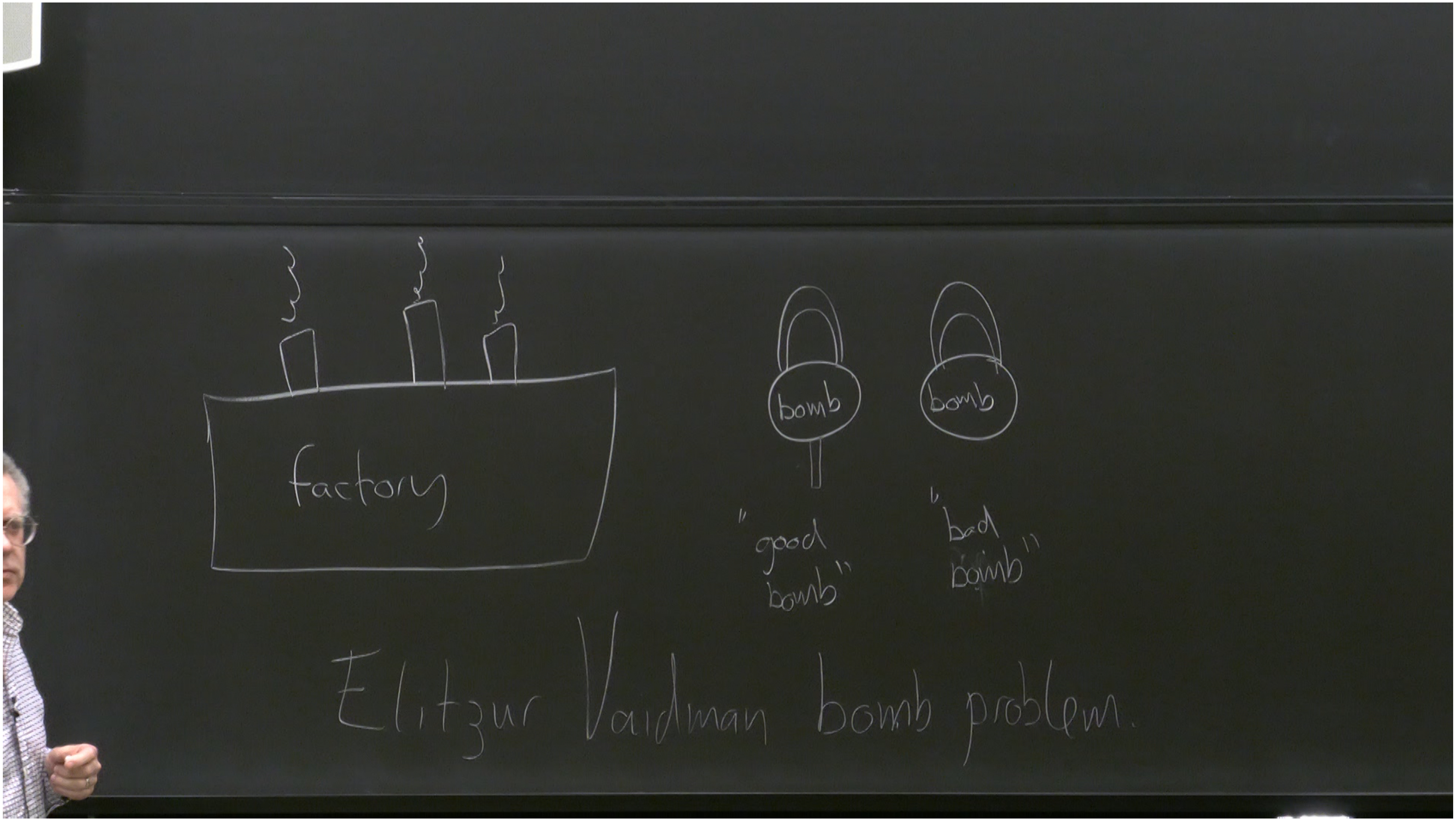
Title: Quantum Foundations Lecture

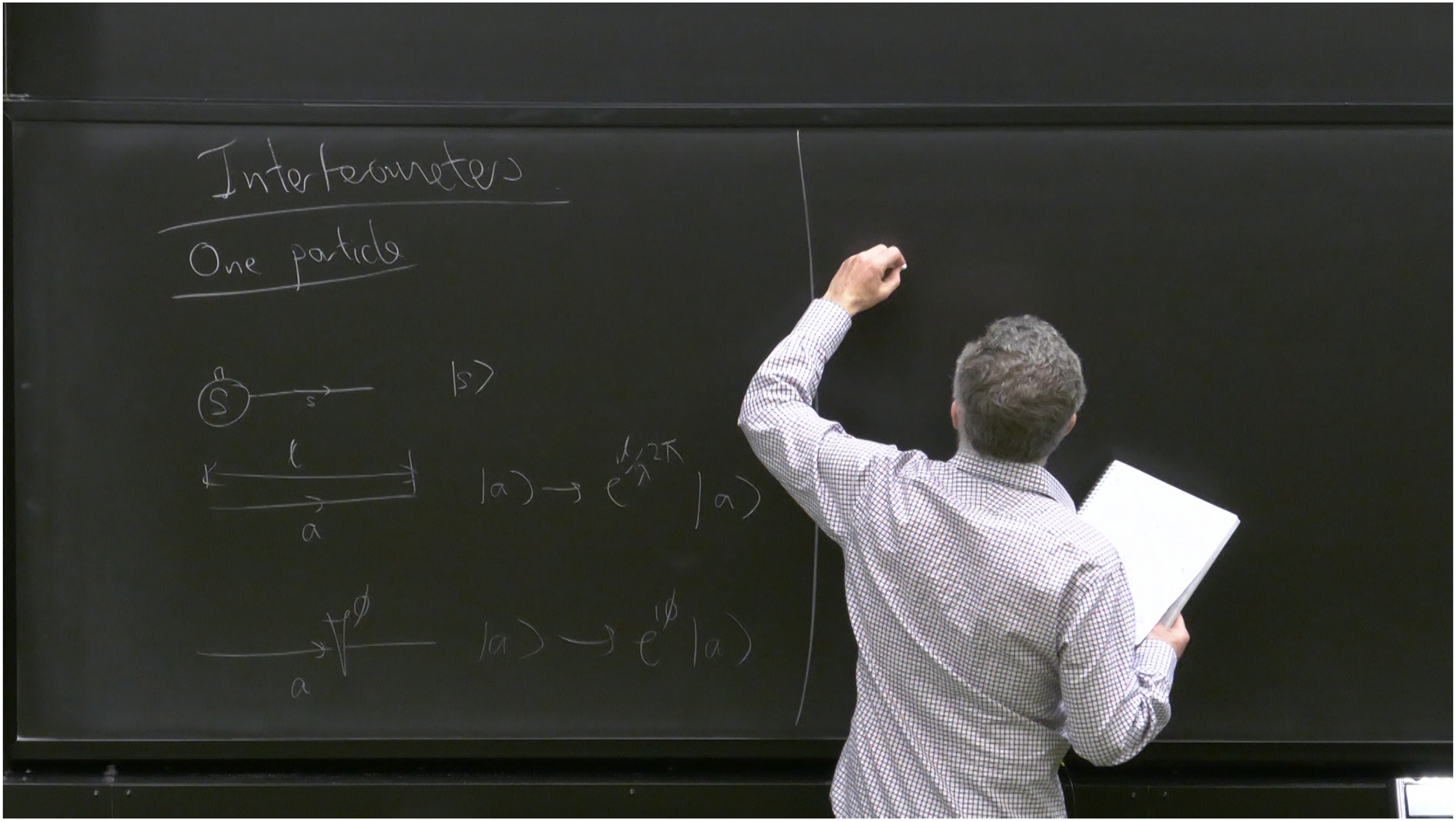
Speakers: Lucien Hardy

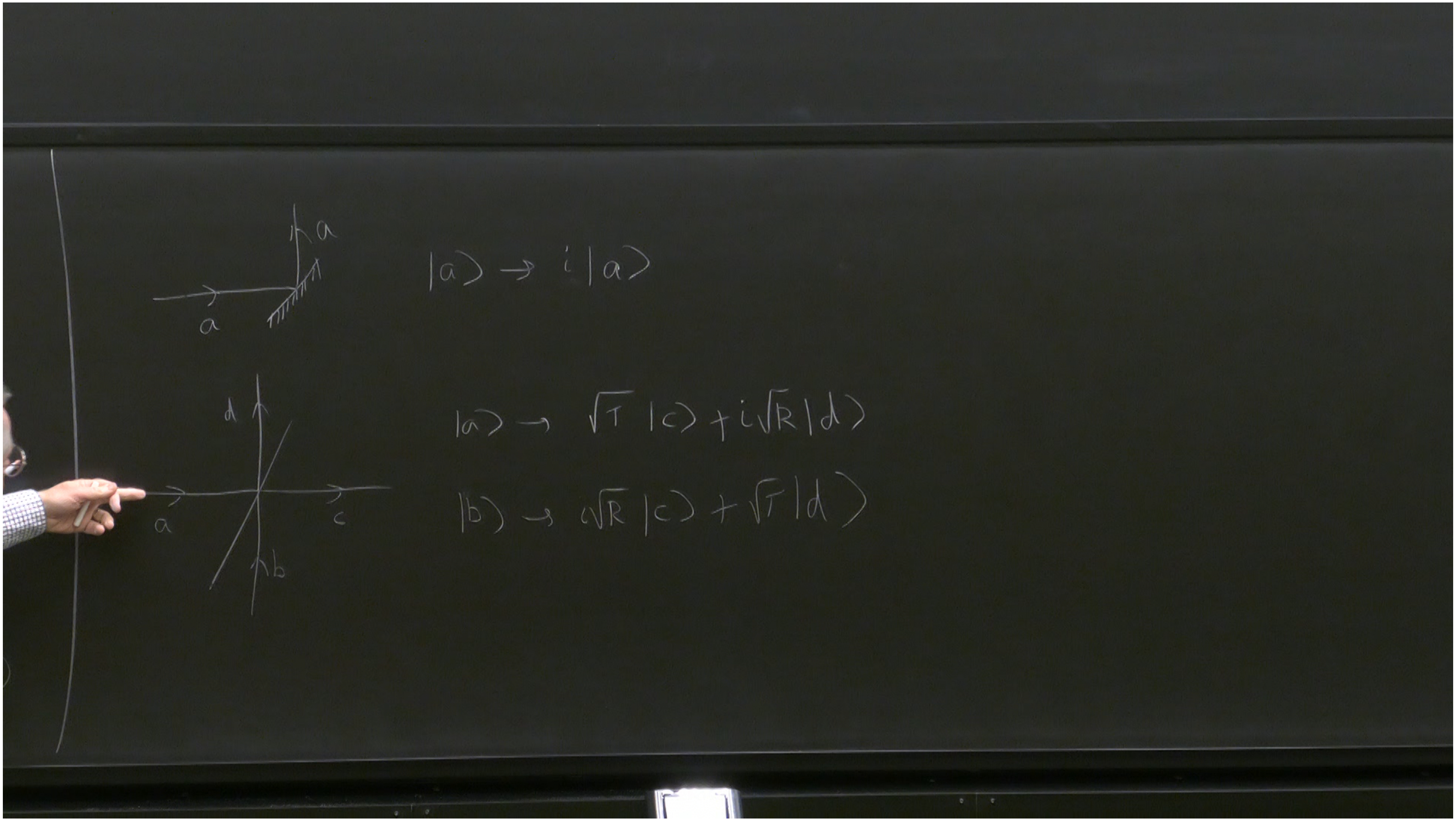
Collection: Quantum Foundations

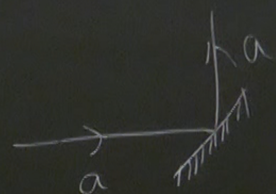
Date: January 08, 2024 - 10:15 AM

URL: https://pirsa.org/24010059

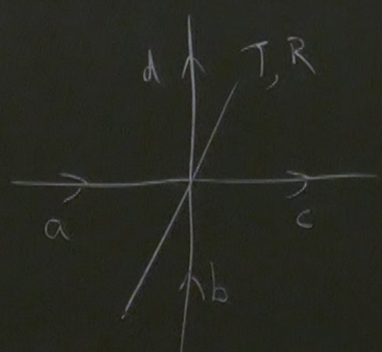

factory
bomb
bomb
"good bomb"
"bad bomb"
Elitzur Vaidman bomb problem.


Interferometers
One particle
S
s
$|s\rangle$
ℓ
a
$|a\rangle \to e^{i\ell 2\pi/\lambda}|a\rangle$
ϕ
a
$|a\rangle \to e^{i\phi}|a\rangle$


a
a
|a⟩ → i|a⟩
d
a
c
b
|a⟩ → √T |c⟩ + i√R |d⟩
|b⟩ → i√R |c⟩ + √T |d⟩

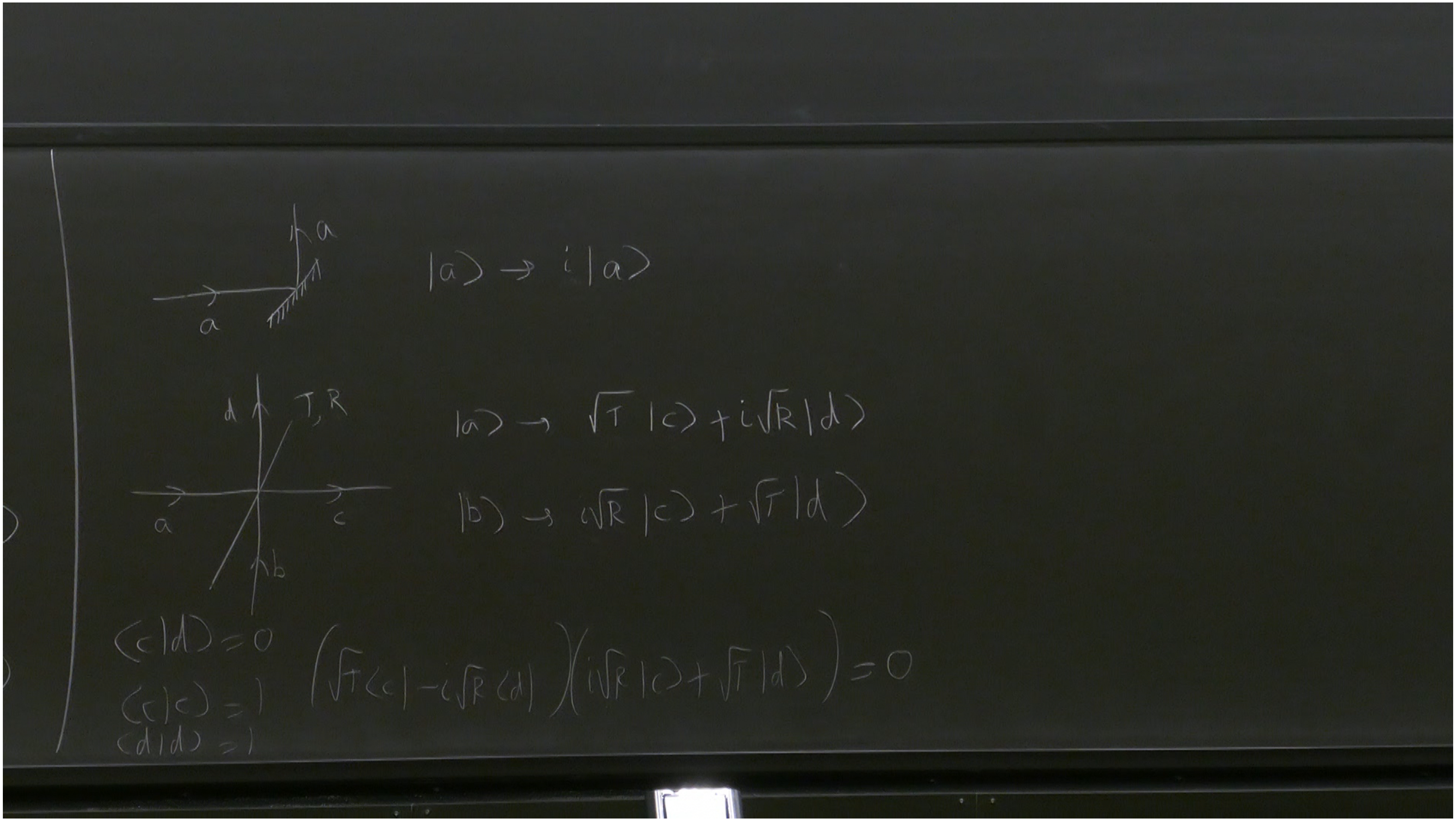


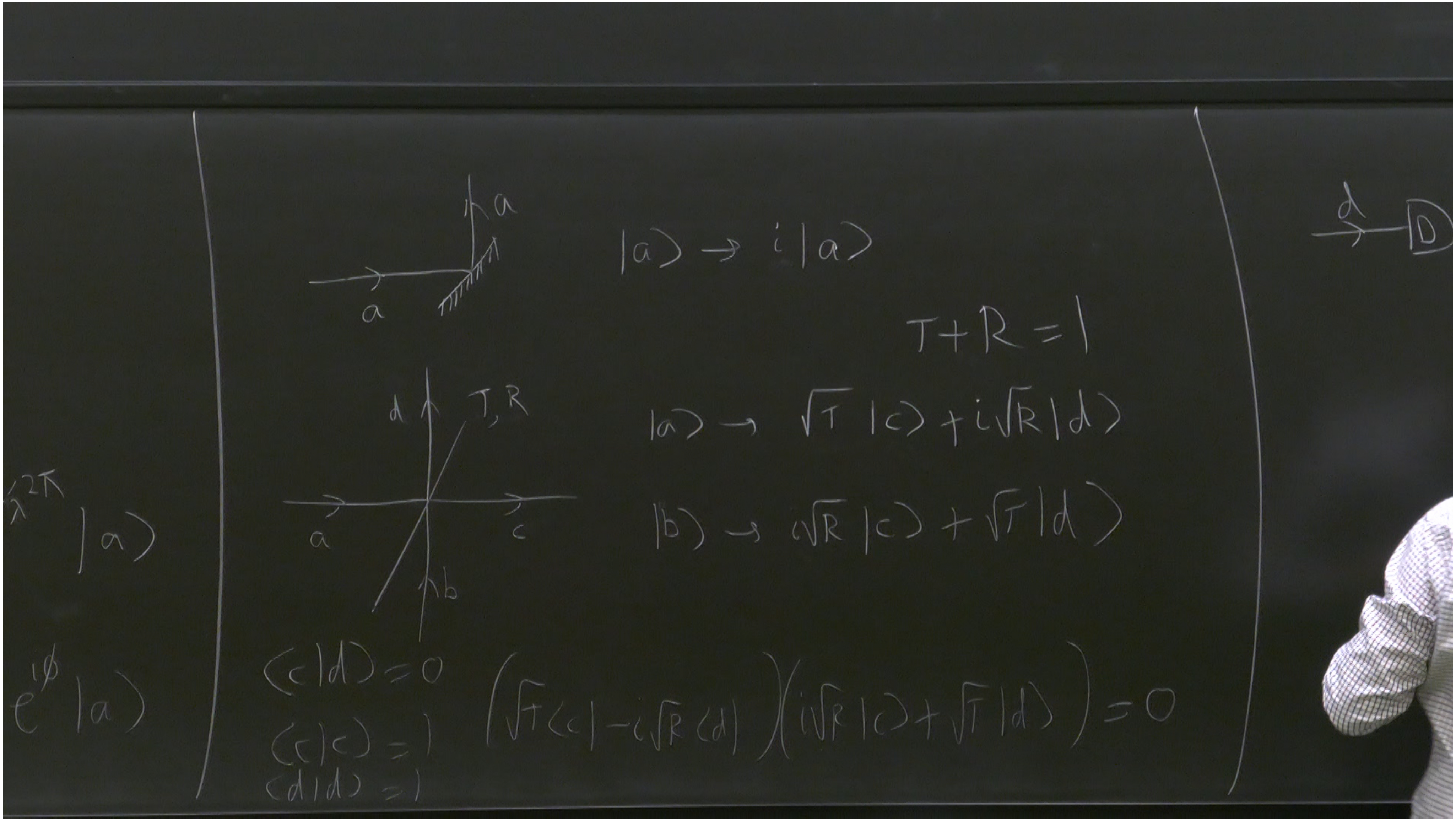
$$|a\rangle \to i|a\rangle$$

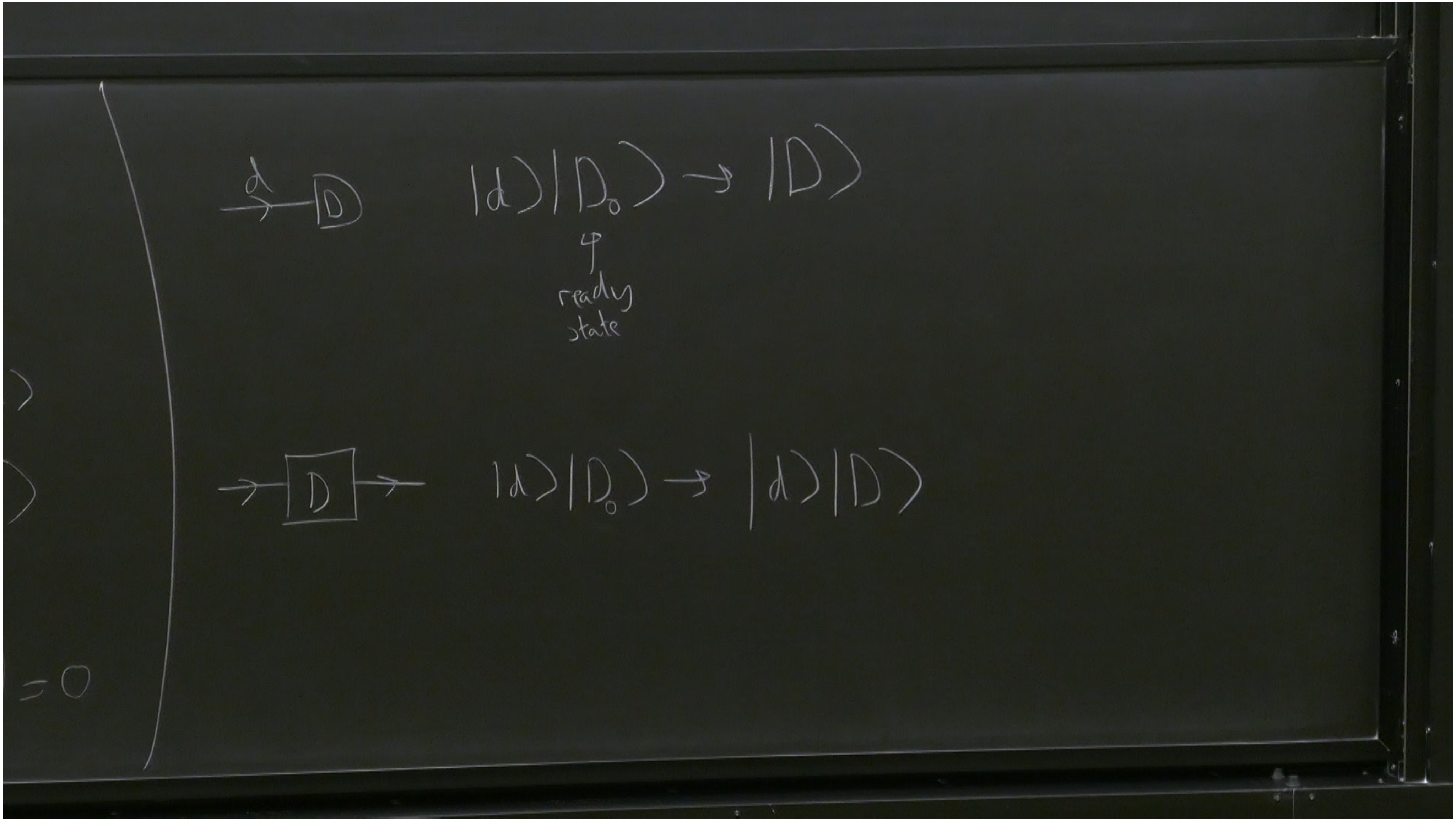


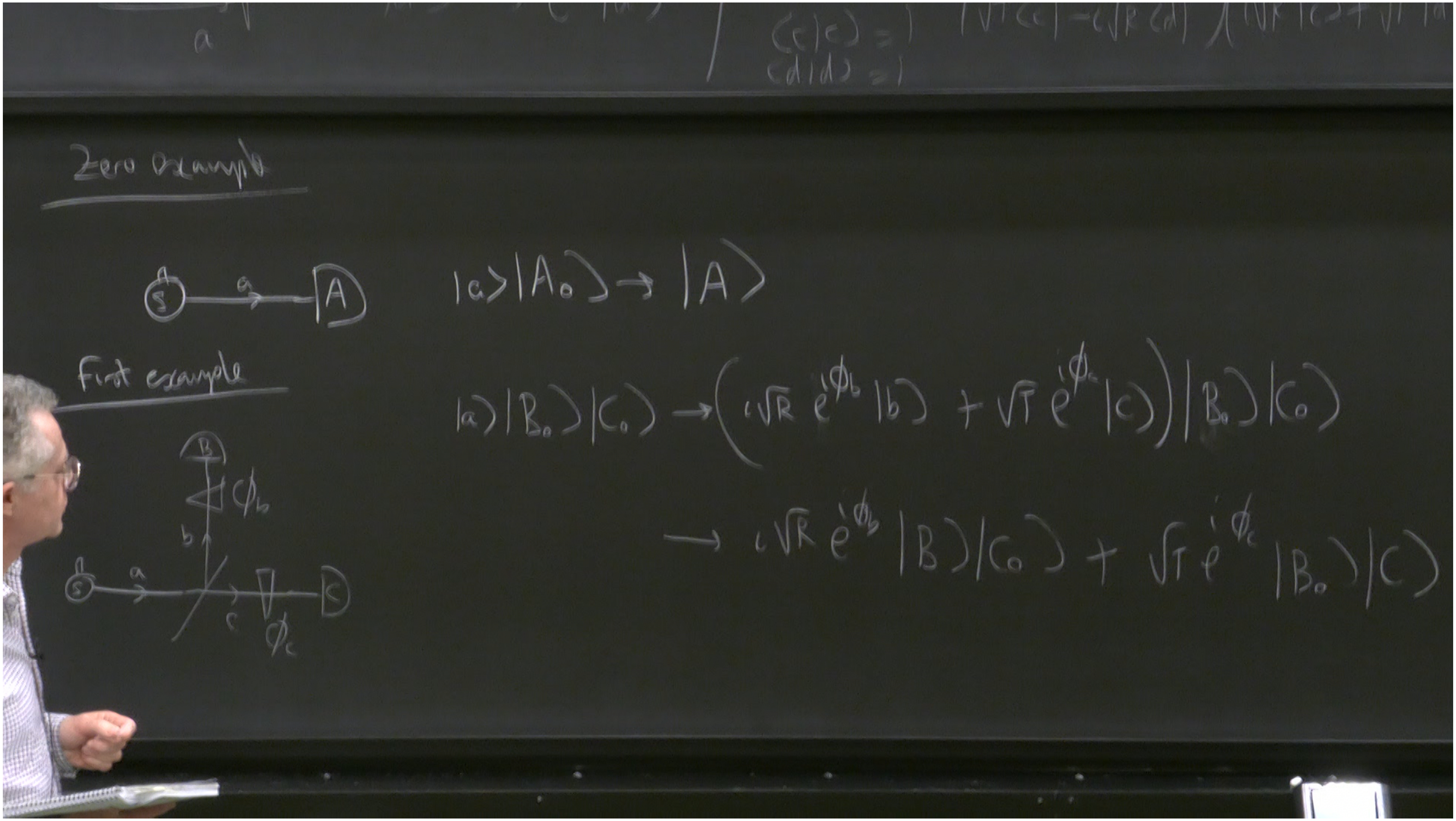
$$|a\rangle \to \sqrt{T}\,|c\rangle + i\sqrt{R}\,|d\rangle$$

$$|b\rangle \to i\sqrt{R}\,|c\rangle + \sqrt{T}\,|d\rangle$$


|a⟩ → i|a⟩
|a⟩ → √T |c⟩ + i√R |d⟩
|b⟩ → i√R |c⟩ + √T |d⟩
⟨c|d⟩ = 0
(√T ⟨c| − i√R ⟨d|)(i√R |c⟩ + √T |d⟩) = 0
⟨c|c⟩ = 1
⟨d|d⟩ = 1
T, R


$|a\rangle \to i|a\rangle$
$T+R=1$
$|a\rangle \to \sqrt{T}\,|c\rangle + i\sqrt{R}\,|d\rangle$
$|b\rangle \to i\sqrt{R}\,|c\rangle + \sqrt{T}\,|d\rangle$
$\langle c|d\rangle = 0$
$\langle c|c\rangle = 1$
$\langle d|d\rangle = 1$
$\left(\sqrt{T}\langle c| - i\sqrt{R}\langle d|\right)\left(i\sqrt{R}\,|c\rangle + \sqrt{T}\,|d\rangle\right) = 0$
$e^{i\phi}|a\rangle$
T, R
a
b
c
d
D


d
D
|d⟩|D₀⟩ → |D⟩
ready
state
D
|d⟩|D₀⟩ → |d⟩|D⟩
=0

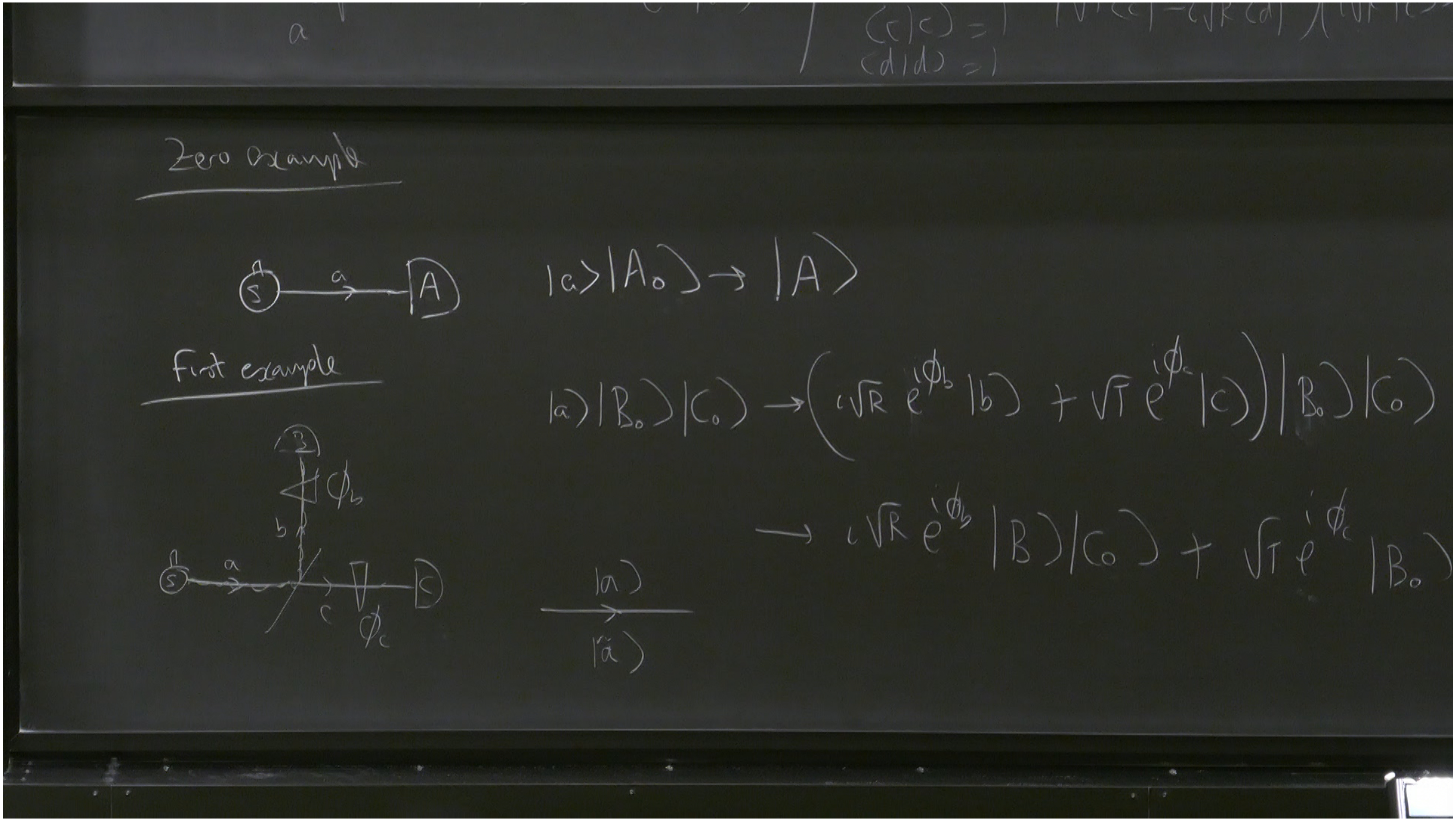

⟨c|c⟩ = 1
⟨d|d⟩ = 1
Zero example
S
a
A
$|a\rangle|A_0\rangle \rightarrow |A\rangle$
First example
$|a\rangle|B_0\rangle|C_0\rangle \rightarrow \left(i\sqrt{R}\, e^{i\phi_b}|b\rangle + \sqrt{T}\, e^{i\phi_c}|c\rangle\right)|B_0\rangle|C_0\rangle$
$\rightarrow i\sqrt{R}\, e^{i\phi_b}|B\rangle|C_0\rangle + \sqrt{T}\, e^{i\phi_c}|B_0\rangle|C\rangle$
B
ϕ_b
b
a
c
C
ϕ_c

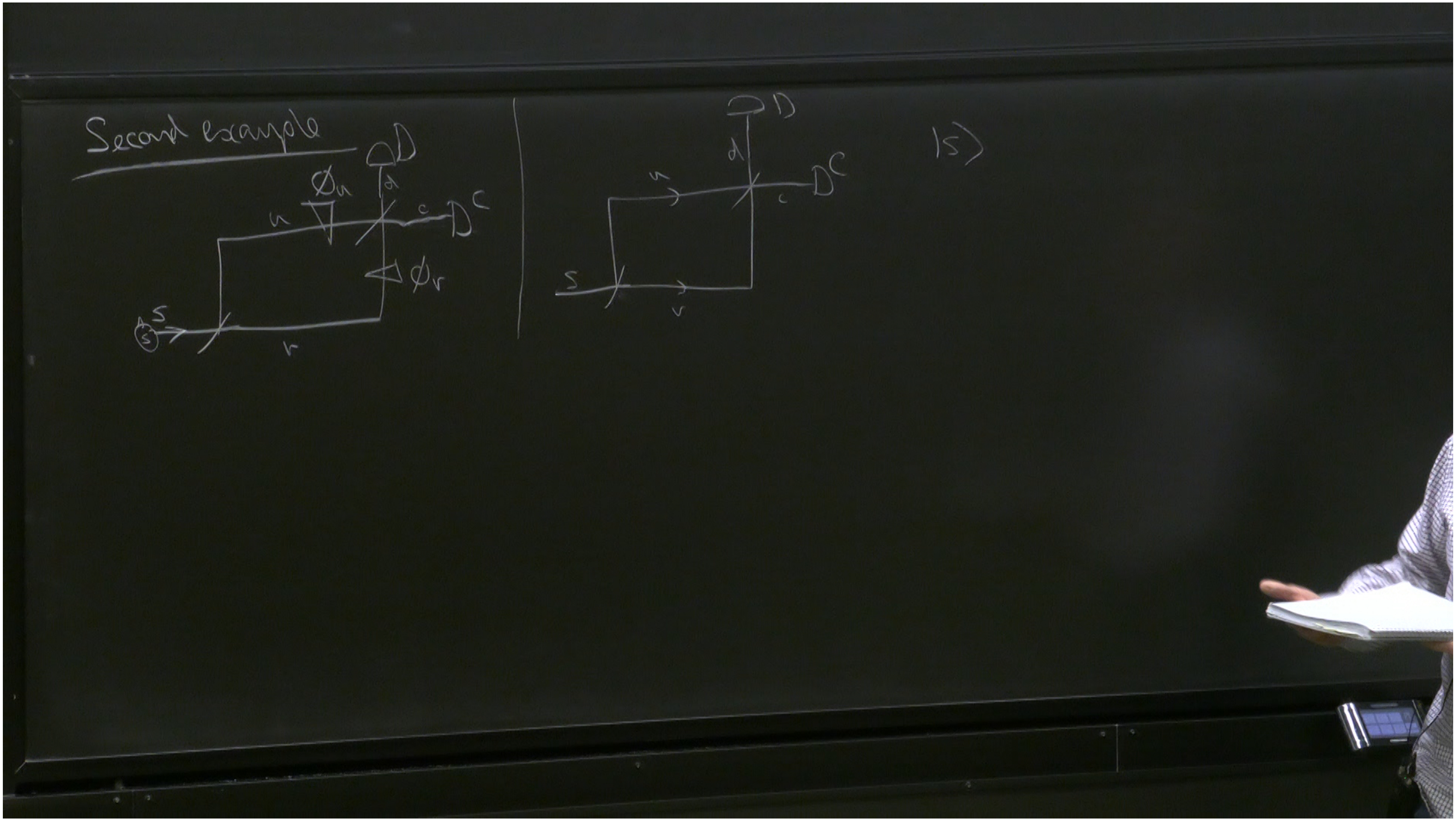
$$\text{prob}(B\,C_0) = |i\sqrt{R}\,e^{i\phi_b}|^2 = R$$

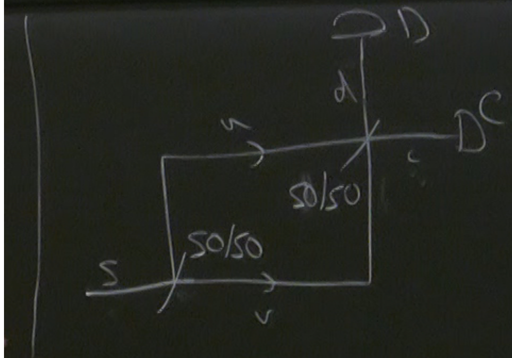
$$\text{prob}(B_0\,C) = T$$

$$\text{prob}(B_0\,C_0) = \text{prob}(B\,C) = 0$$

$|C\rangle$


Zero example
$|a\rangle|A_0\rangle \to |A\rangle$
First example
$|a\rangle|B_0\rangle|C_0\rangle \to \left(i\sqrt{R}\, e^{i\phi_b}|b\rangle + \sqrt{T}\, e^{i\phi_c}|c\rangle\right)|B_0\rangle|C_0\rangle$
$\to i\sqrt{R}\, e^{i\phi_b}|B\rangle|C_0\rangle + \sqrt{T}\, e^{i\phi_c}|B_0\rangle$
$|a\rangle$
$|\tilde{a}\rangle$
$\langle c|c\rangle = 1$
$\langle d|d\rangle = 1$

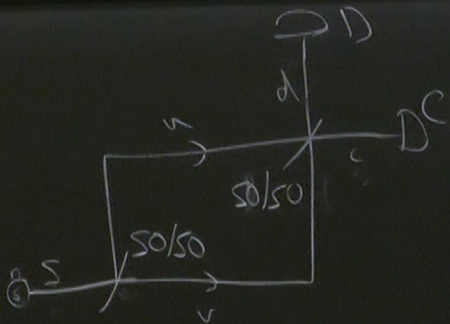

Second example
D
D^c
Ø_u
Ø_r
|s⟩



$$|s\rangle \to \frac{i}{\sqrt{2}}|u\rangle + \frac{1}{\sqrt{2}}|v\rangle$$

$$\to \frac{i}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|c\rangle + \frac{i}{\sqrt{2}}|d\rangle\right) + \frac{1}{\sqrt{2}}\left(\frac{i}{\sqrt{2}}|c\rangle + \frac{1}{\sqrt{2}}|d\rangle\right)$$

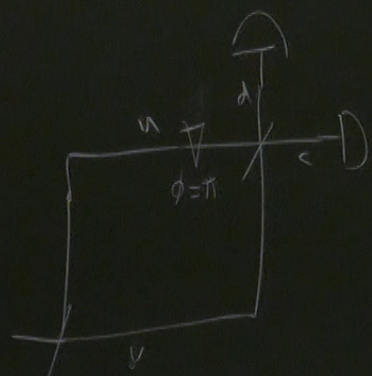
$$= i|c\rangle$$



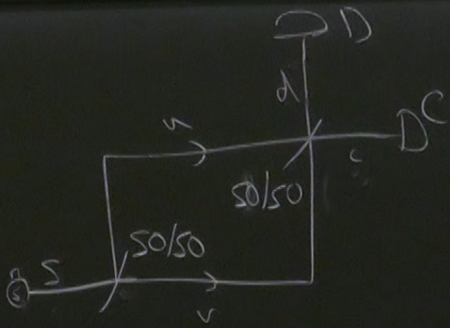
$$|s\rangle \to \frac{i}{\sqrt{2}}|u\rangle + \frac{1}{\sqrt{2}}|v\rangle$$

$$\to \frac{i}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|c\rangle + \frac{i}{\sqrt{2}}|d\rangle\right) + \frac{1}{\sqrt{2}}\left(\frac{i}{\sqrt{2}}|c\rangle + \frac{1}{\sqrt{2}}|d\rangle\right)$$

$$= i|c\rangle$$ Detector C always fires.



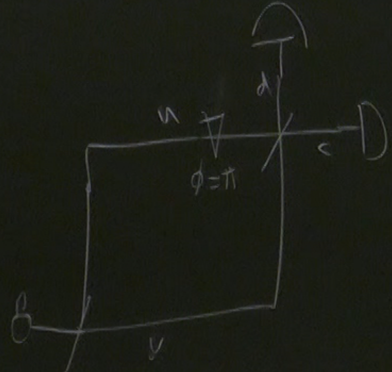
$$|s\rangle \to \cdots\cdots \to |d\rangle$$



$$|s\rangle \to \frac{i}{\sqrt{2}}|u\rangle + \frac{1}{\sqrt{2}}|v\rangle$$

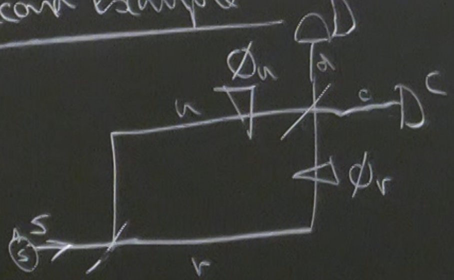
$$\to \frac{i}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|c\rangle + \frac{i}{\sqrt{2}}|d\rangle\right) + \frac{1}{\sqrt{2}}\left(\frac{i}{\sqrt{2}}|c\rangle + \frac{1}{\sqrt{2}}|d\rangle\right)$$

$= i|c\rangle$ Detector C always fires.

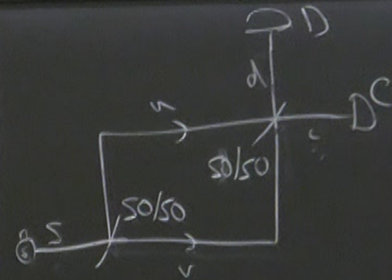


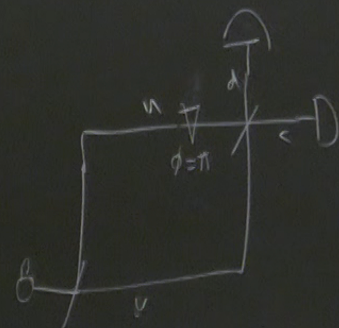
$|s\rangle \to \dots \to |d\rangle$ Detector D always fires

Second example



Mach Zehnder



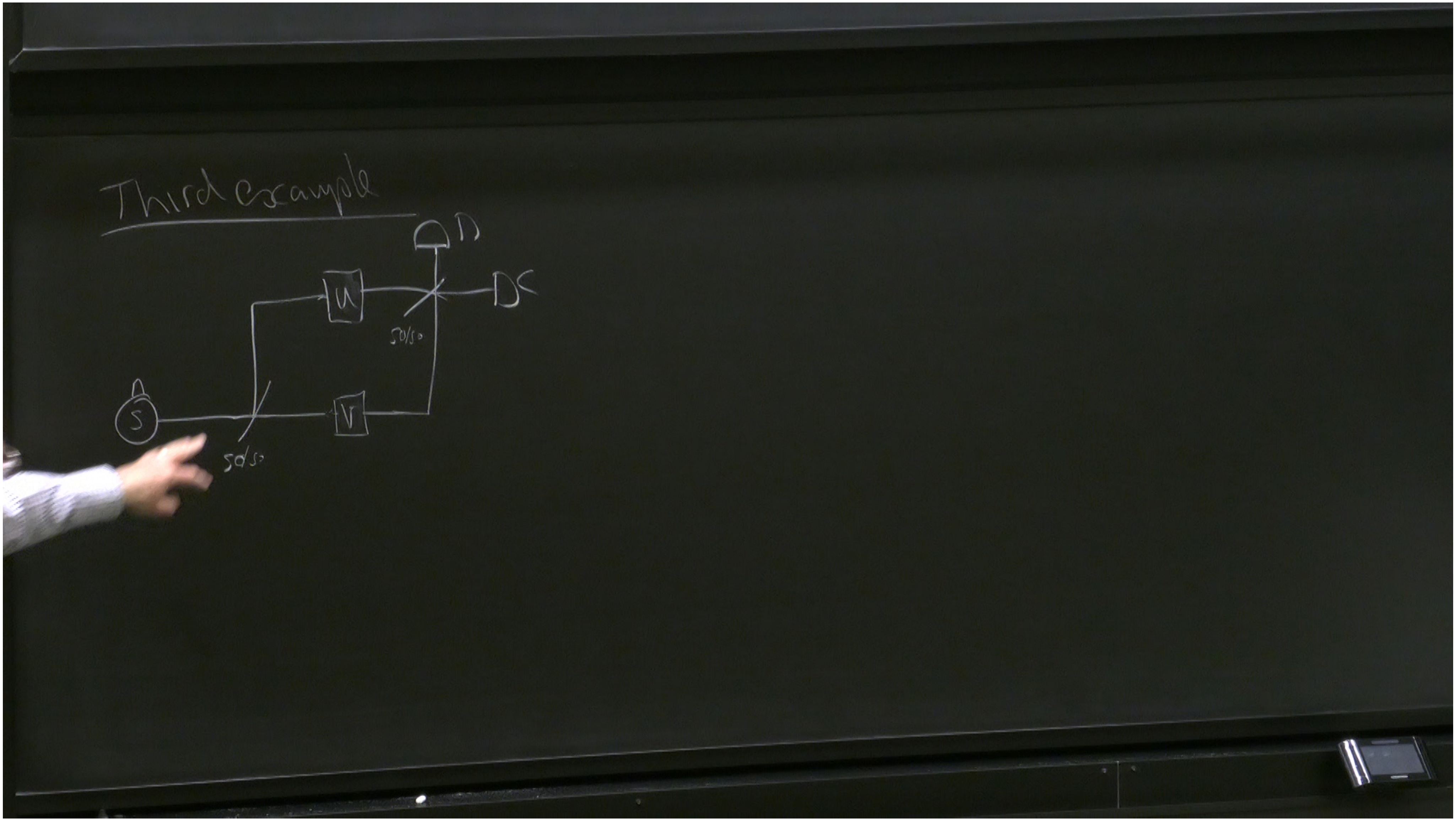


$$|s\rangle \to \frac{i}{\sqrt{2}}|u\rangle + \frac{1}{\sqrt{2}}|v\rangle$$

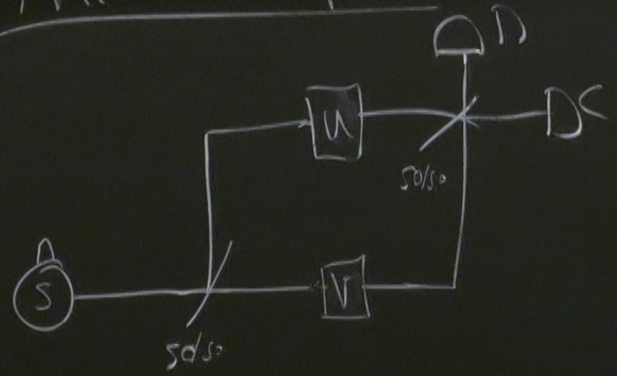
$$\to \frac{i}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|c\rangle + \frac{i}{\sqrt{2}}|d\rangle\right) + \frac{1}{\sqrt{2}}\left(\frac{i}{\sqrt{2}}|c\rangle + \frac{1}{\sqrt{2}}|d\rangle\right)$$

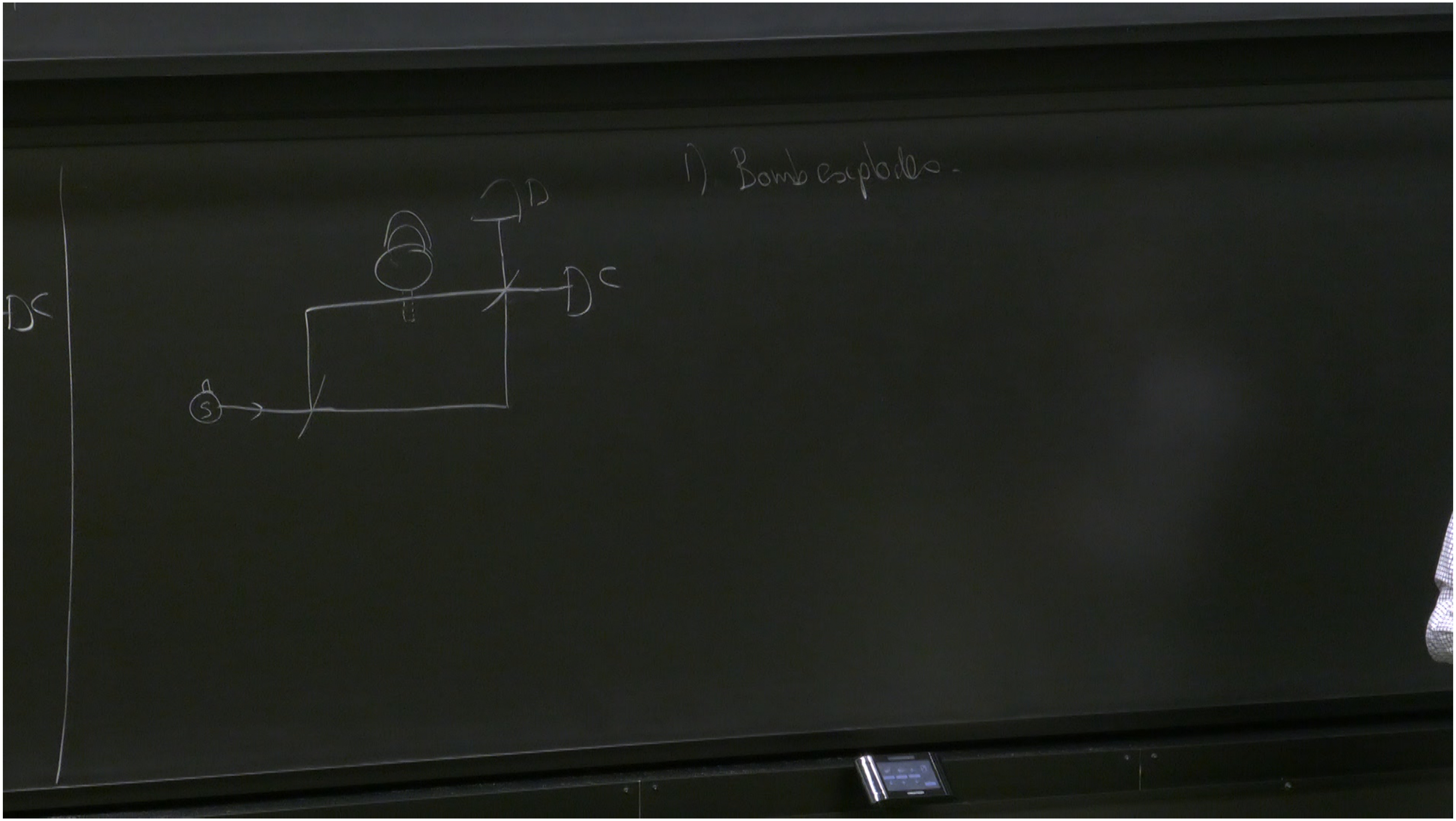
$$= i|c\rangle$$ Detector C always fires.

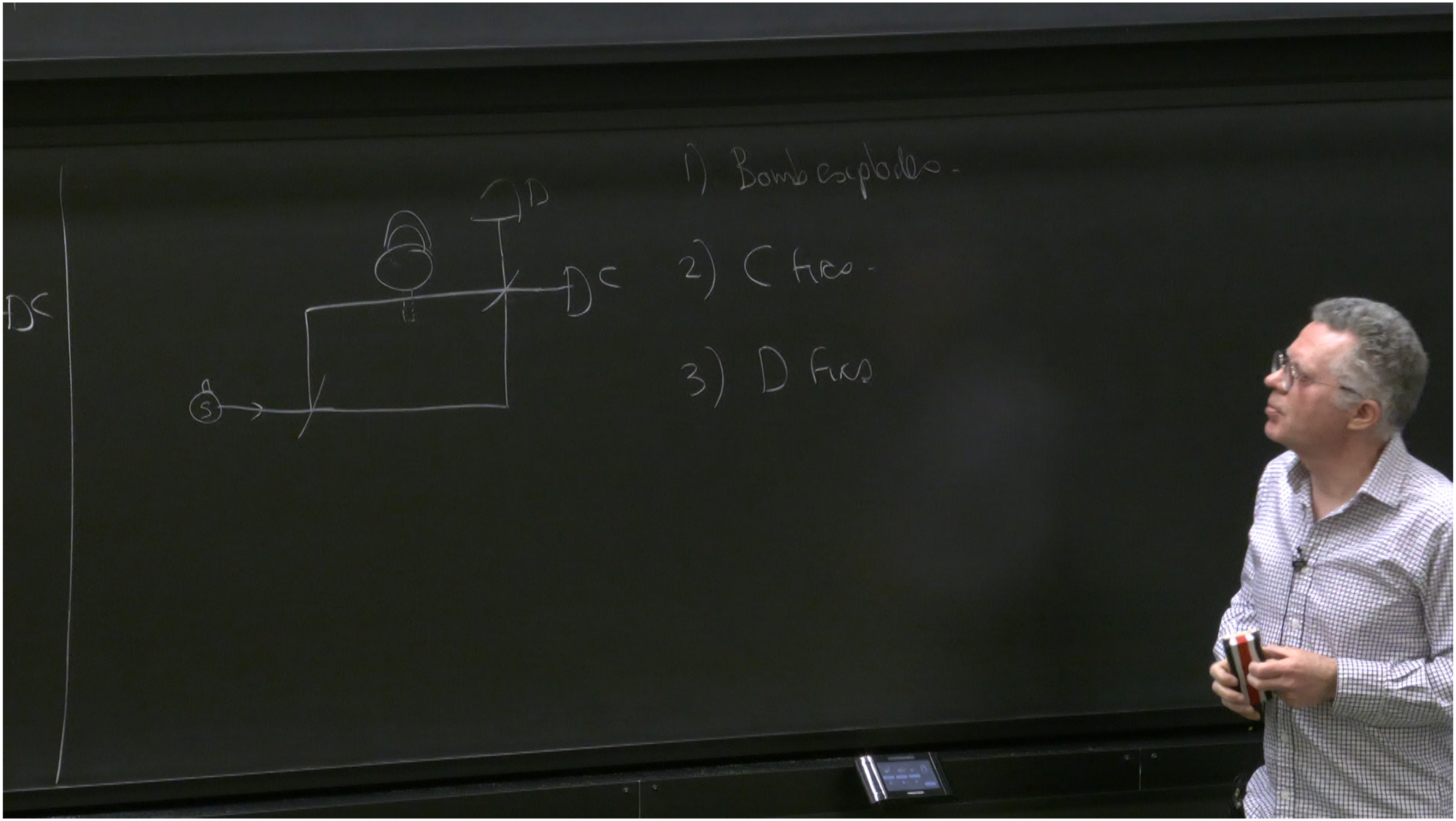
$$|s\rangle \to \cdots \to |d\rangle$$ Detector D always fires

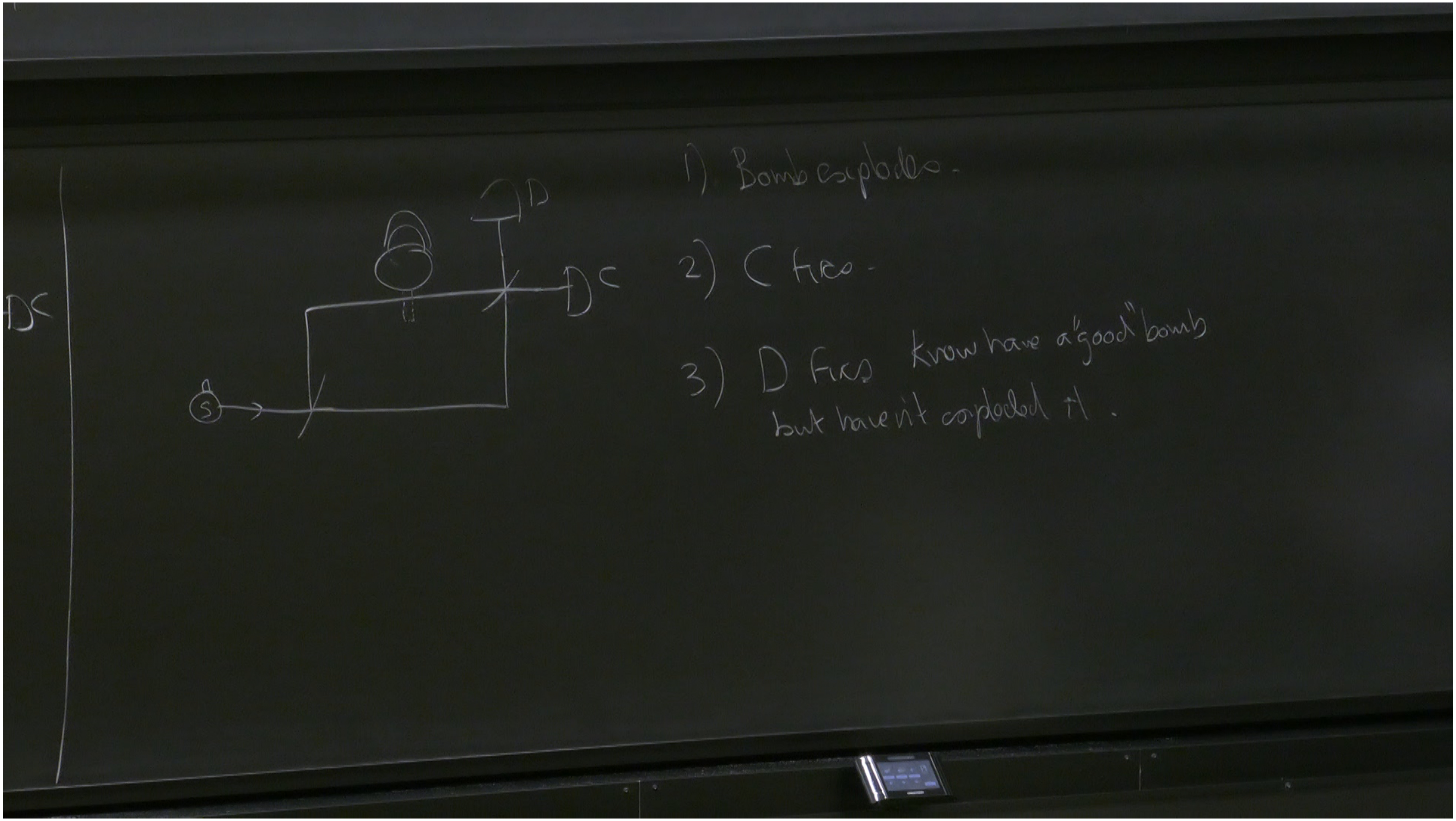

Third example
D
U
50/50
V
S
50/50

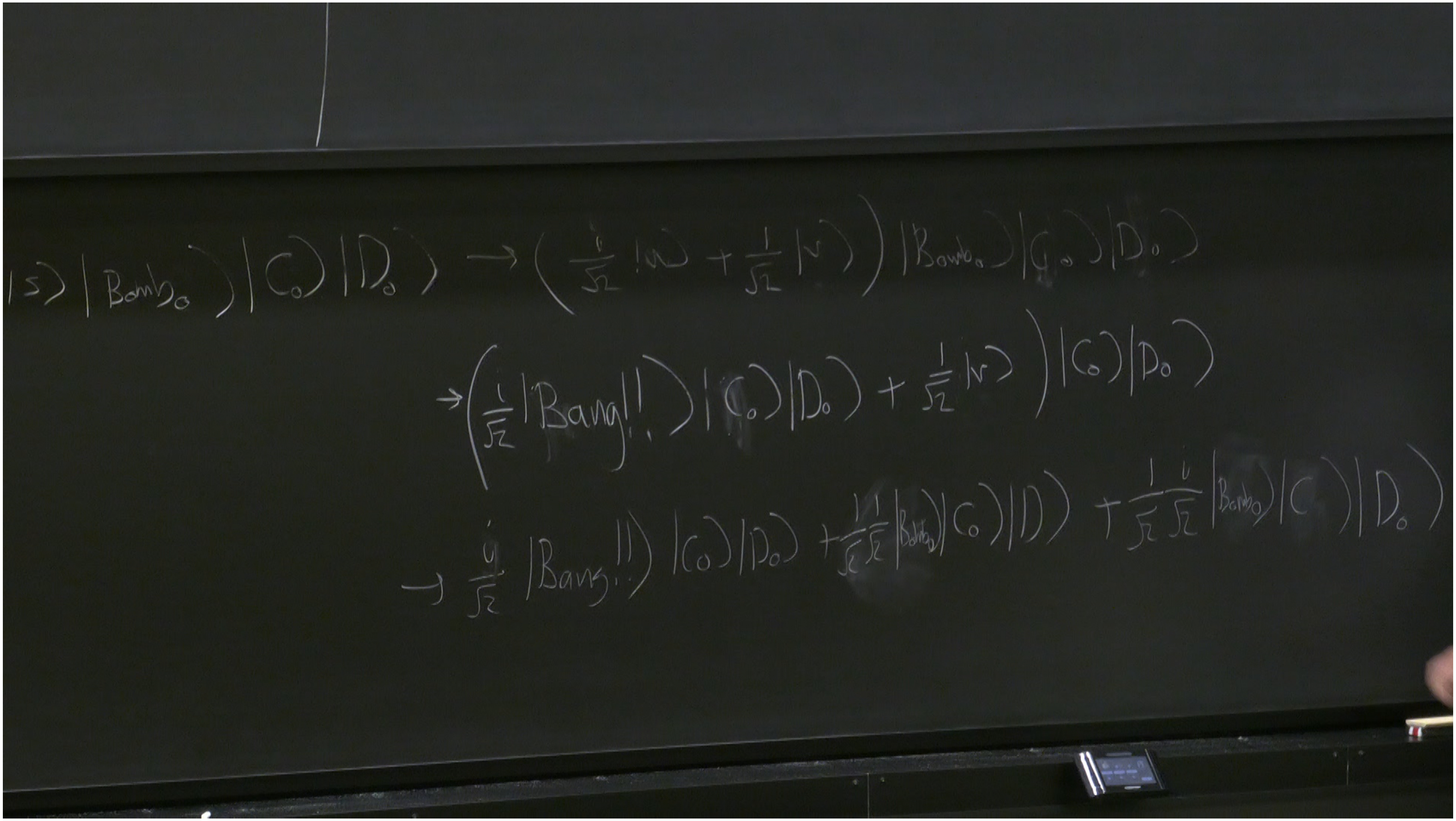
Third example

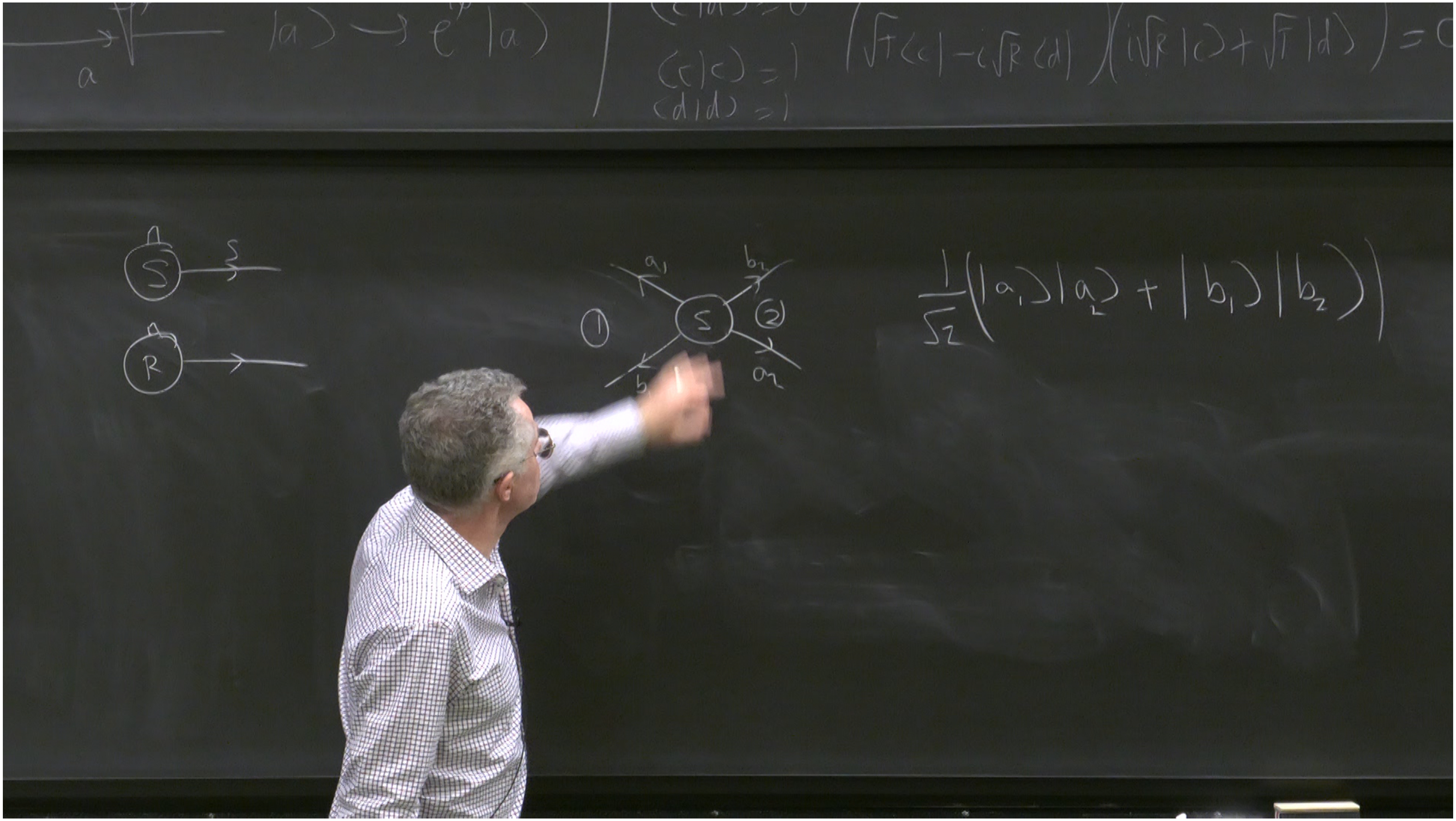



1) Bomb explodes.
D
D^c
S

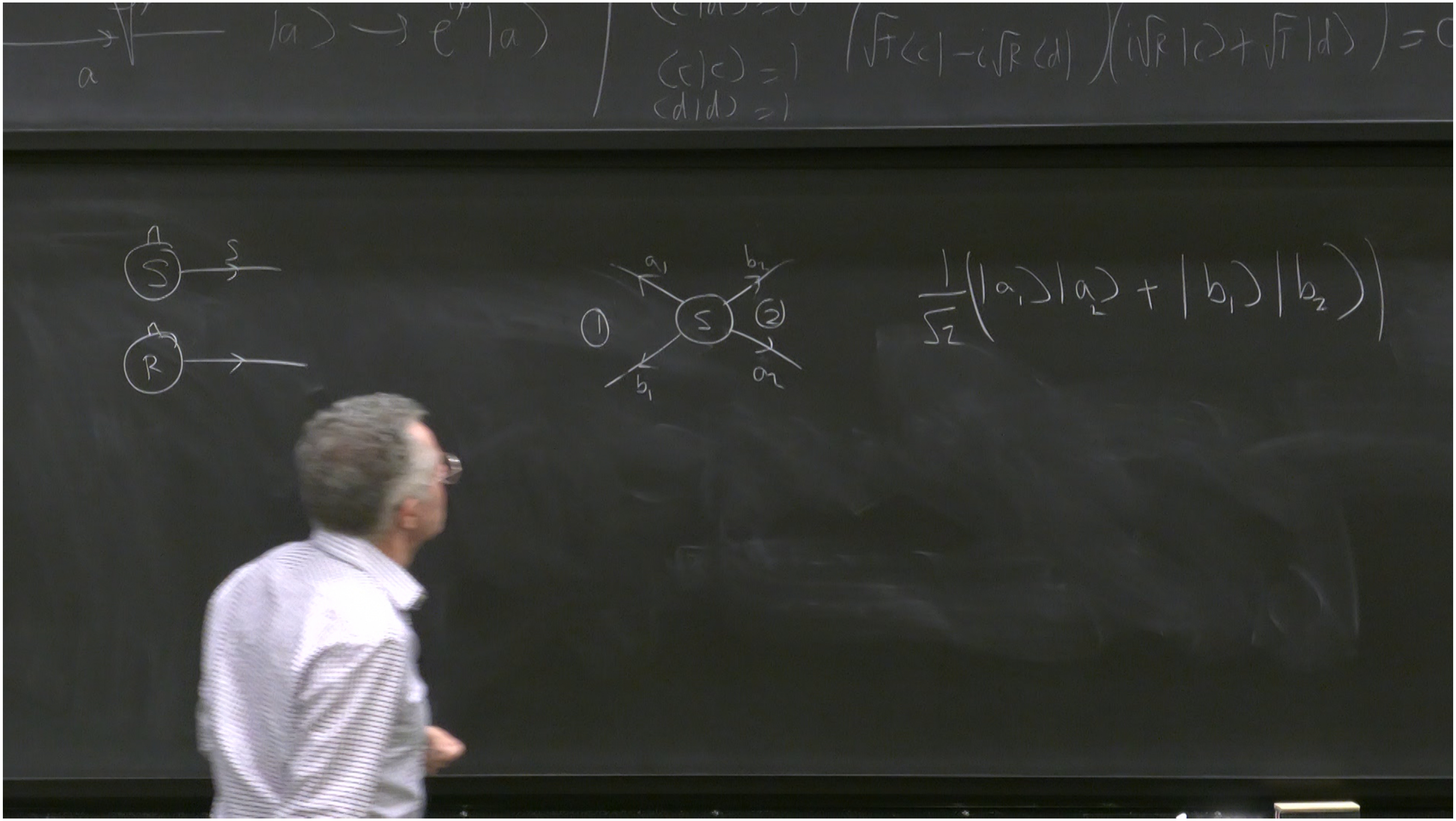

1) Bomb explodes.
2) C fires.
3) D fires
D
S


1) Bomb explodes.
2) C fires.
3) D fires know have a "good" bomb
but haven't exploded it.
D
C
S

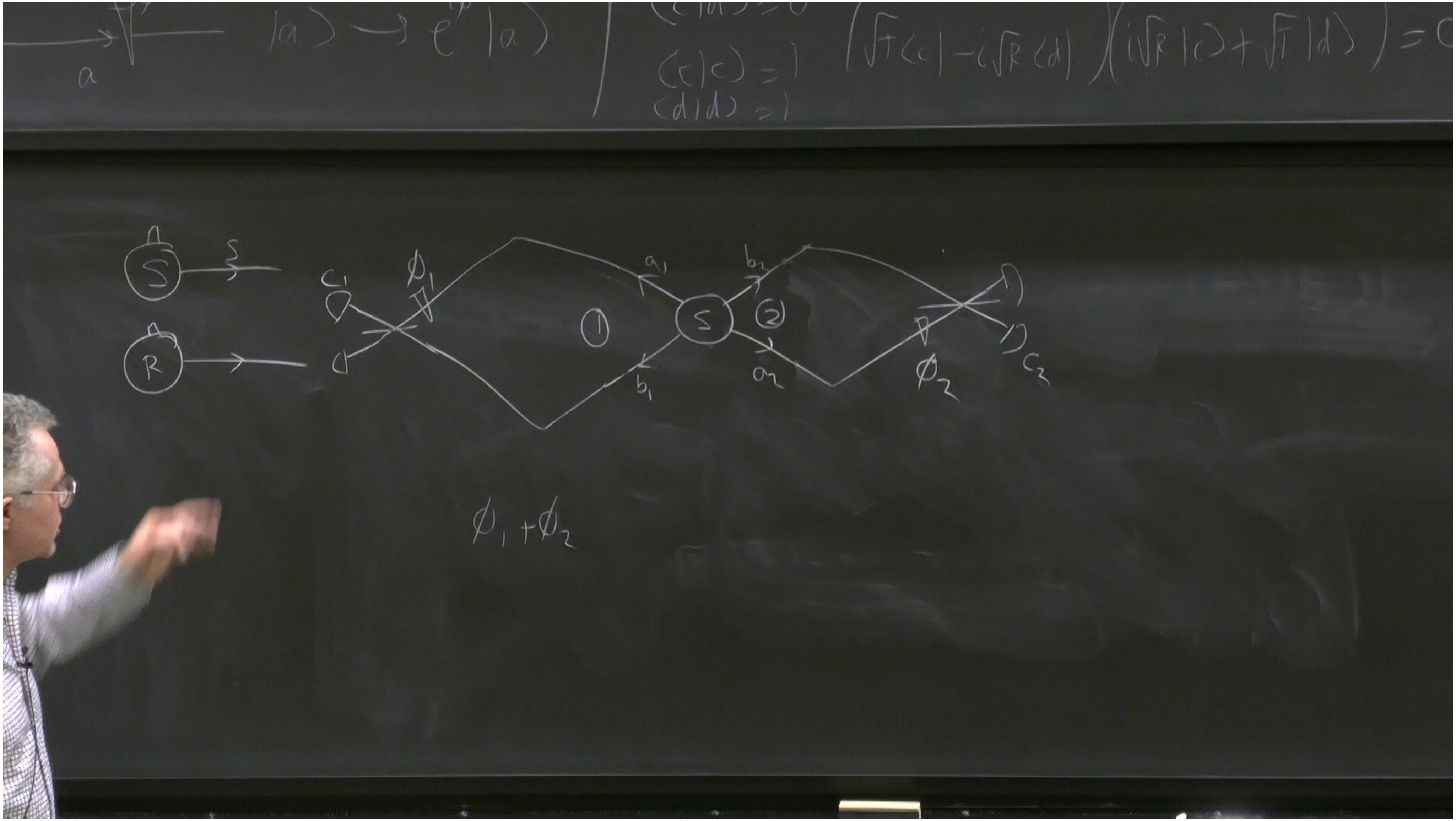

$|S\rangle|Bomb_0\rangle|C_0\rangle|D_0\rangle \rightarrow \left(\frac{i}{\sqrt{2}}|W\rangle + \frac{1}{\sqrt{2}}|V\rangle\right)|Bomb_0\rangle|C_0\rangle|D_0\rangle$
$\rightarrow \left(\frac{i}{\sqrt{2}}|Bang!!\rangle|C_0\rangle|D_0\rangle + \frac{1}{\sqrt{2}}|V\rangle\right)|C_0\rangle|D_0\rangle$
$\rightarrow \frac{i}{\sqrt{2}}|Bang!!\rangle|C_0\rangle|D_0\rangle + \frac{1}{\sqrt{2}}\frac{1}{\sqrt{2}}|Bomb_0\rangle|C_0\rangle|D\rangle + \frac{1}{\sqrt{2}}\frac{i}{\sqrt{2}}|Bomb_0\rangle|C\rangle|D_0\rangle$

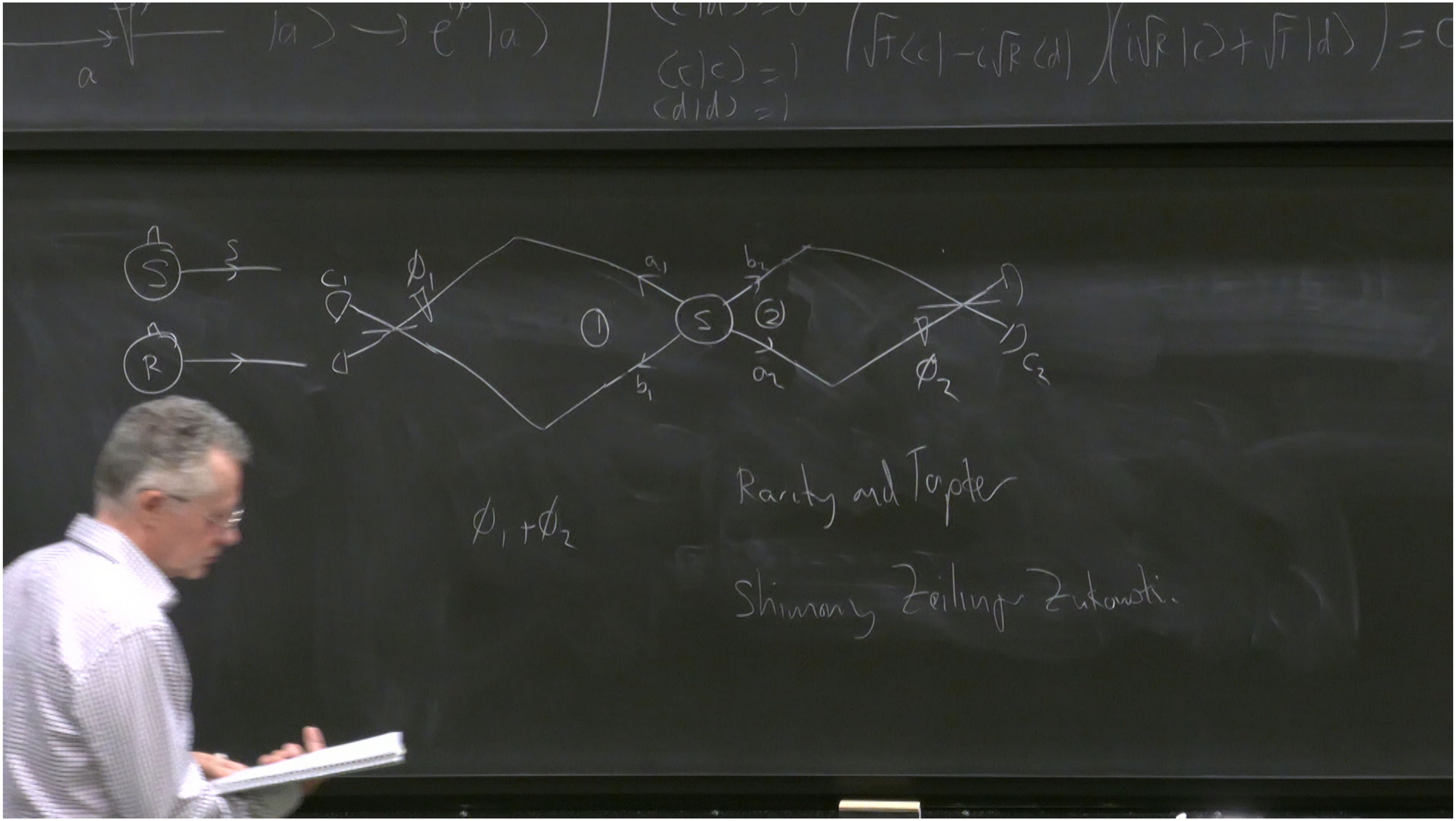


|a⟩ → e |a⟩
⟨c|c⟩ = 1
⟨d|d⟩ = 1
(√T ⟨c| − i√R ⟨d|)(i√R |c⟩ + √T |d⟩) = 0
1/√2 (|a₁⟩|a₂⟩ + |b₁⟩|b₂⟩)



$|a\rangle \to e^{i\varphi}|a\rangle$
$\langle c|c\rangle = 1$
$\langle d|d\rangle = 1$
$(\sqrt{T}\langle c| - i\sqrt{R}\langle d|)(i\sqrt{R}|c\rangle + \sqrt{T}|d\rangle) = 0$
S
R
a_1
b_2
b_1
a_2
1
2
$\frac{1}{\sqrt{2}}(|a_1\rangle|a_2\rangle + |b_1\rangle|b_2\rangle)$




Rarity and Tapster
Shimony Zeilinger Zukowski
$\phi_1 + \phi_2$