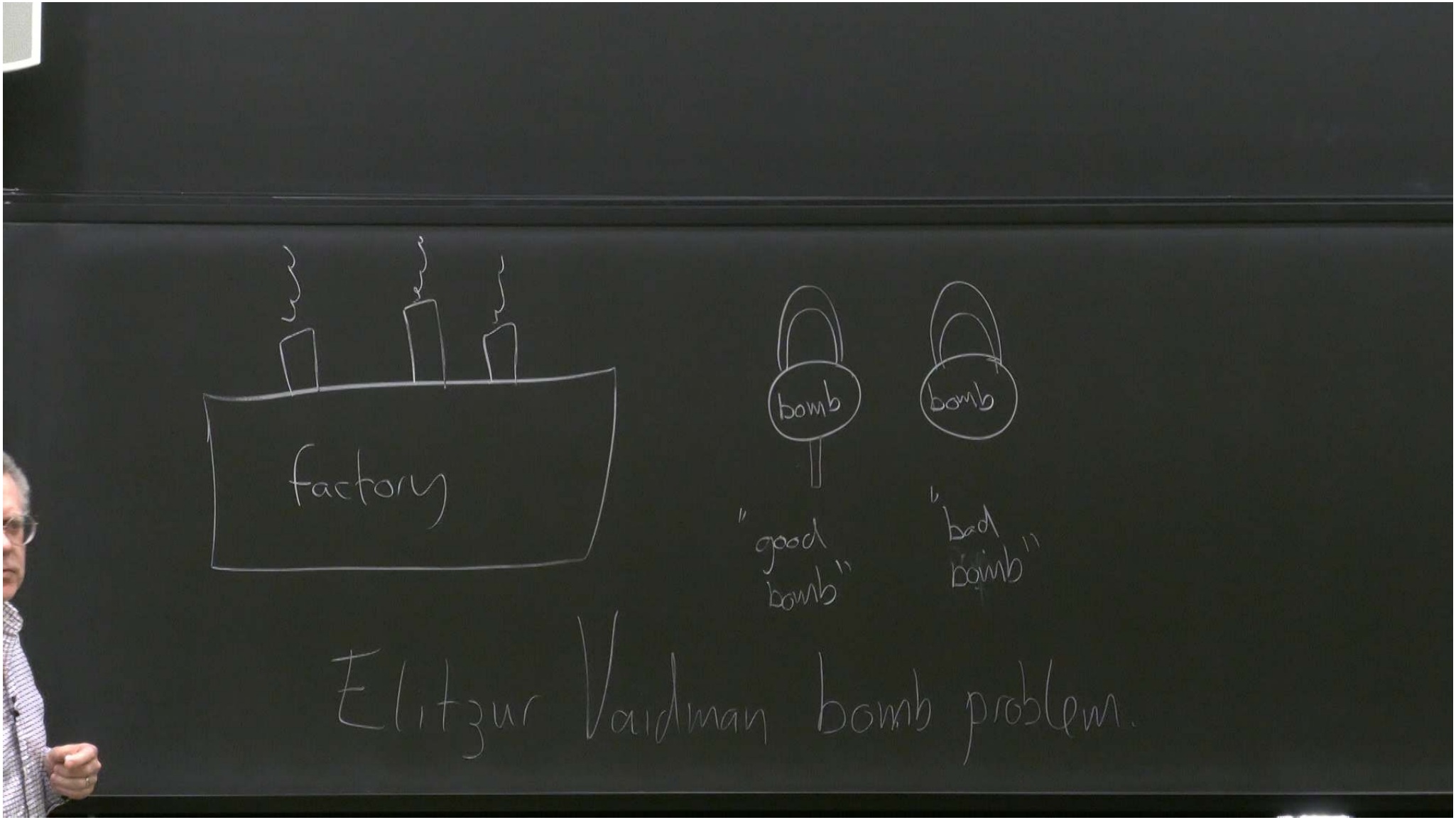
Title: Quantum Foundations Lecture

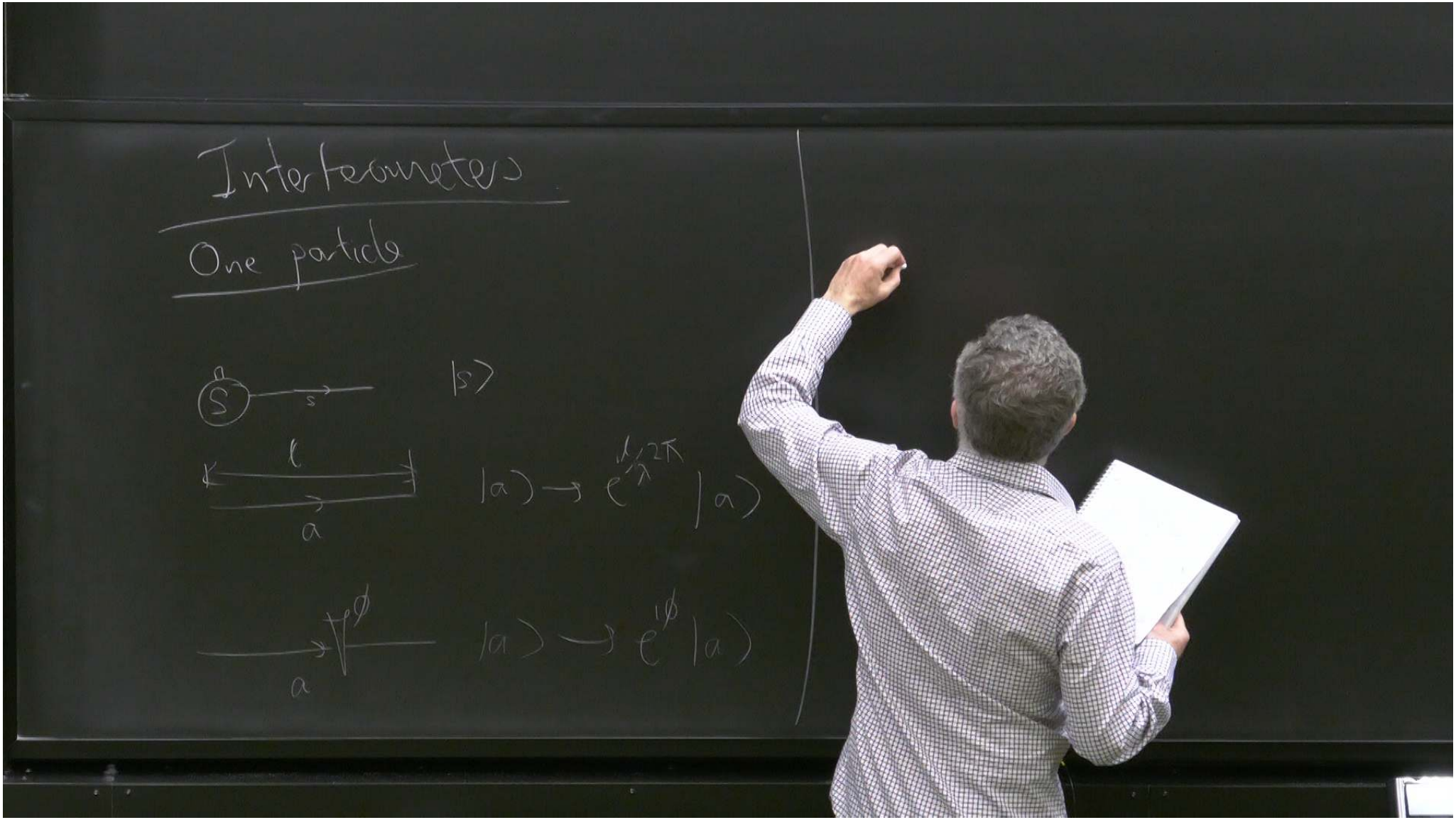
Speakers: Lucien Hardy

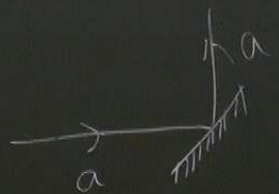
Collection: Quantum Foundations

Date: January 08, 2024 - 10:15 AM

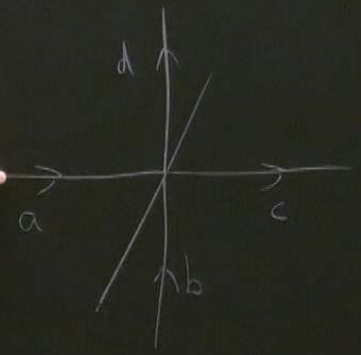
URL: https://pirsa.org/24010059


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


Interferometers
One particle
S
s
|s⟩
ℓ
a
|a⟩ → e^{i 2π/λ ℓ} |a⟩
a
|a⟩ → e^{iφ} |a⟩

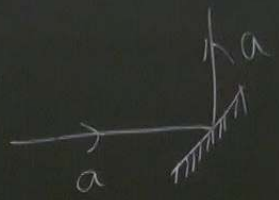


$|a\rangle \rightarrow i|a\rangle$

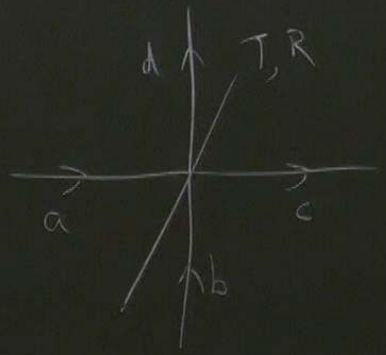


$|a\rangle \rightarrow \sqrt{T}\,|c\rangle + i\sqrt{R}\,|d\rangle$

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

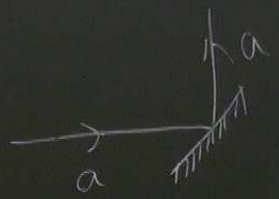


$|a\rangle \rightarrow i|a\rangle$

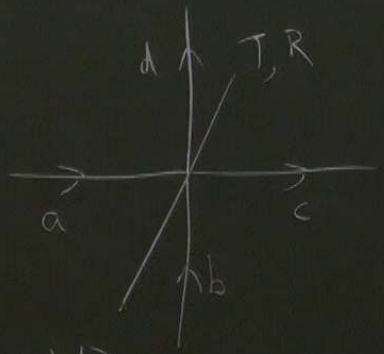


$|a\rangle \rightarrow \sqrt{T}\,|c\rangle + i\sqrt{R}\,|d\rangle$

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



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



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

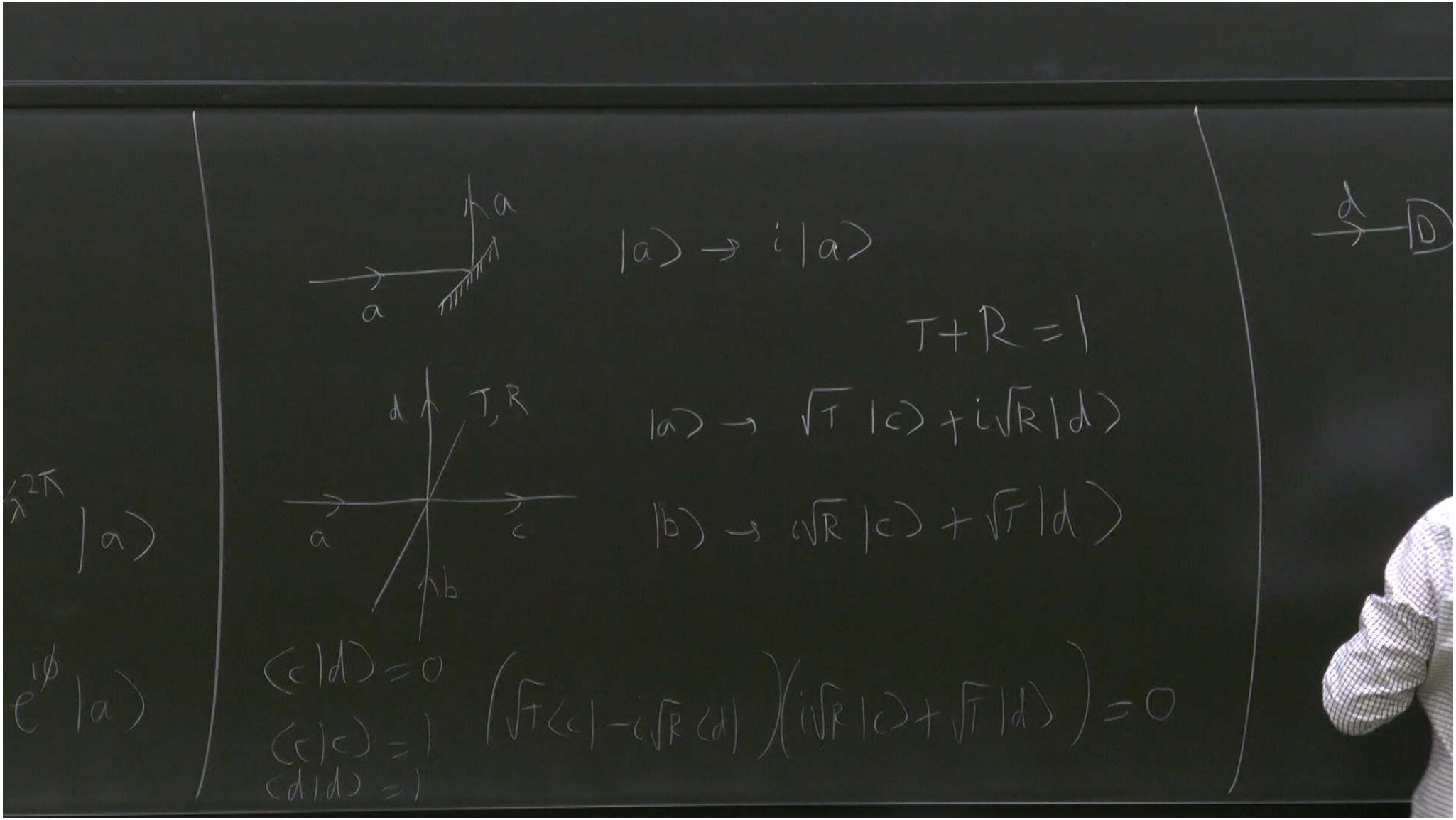
$|b\rangle \to i\sqrt{R}|c\rangle + \sqrt{T}|d\rangle$

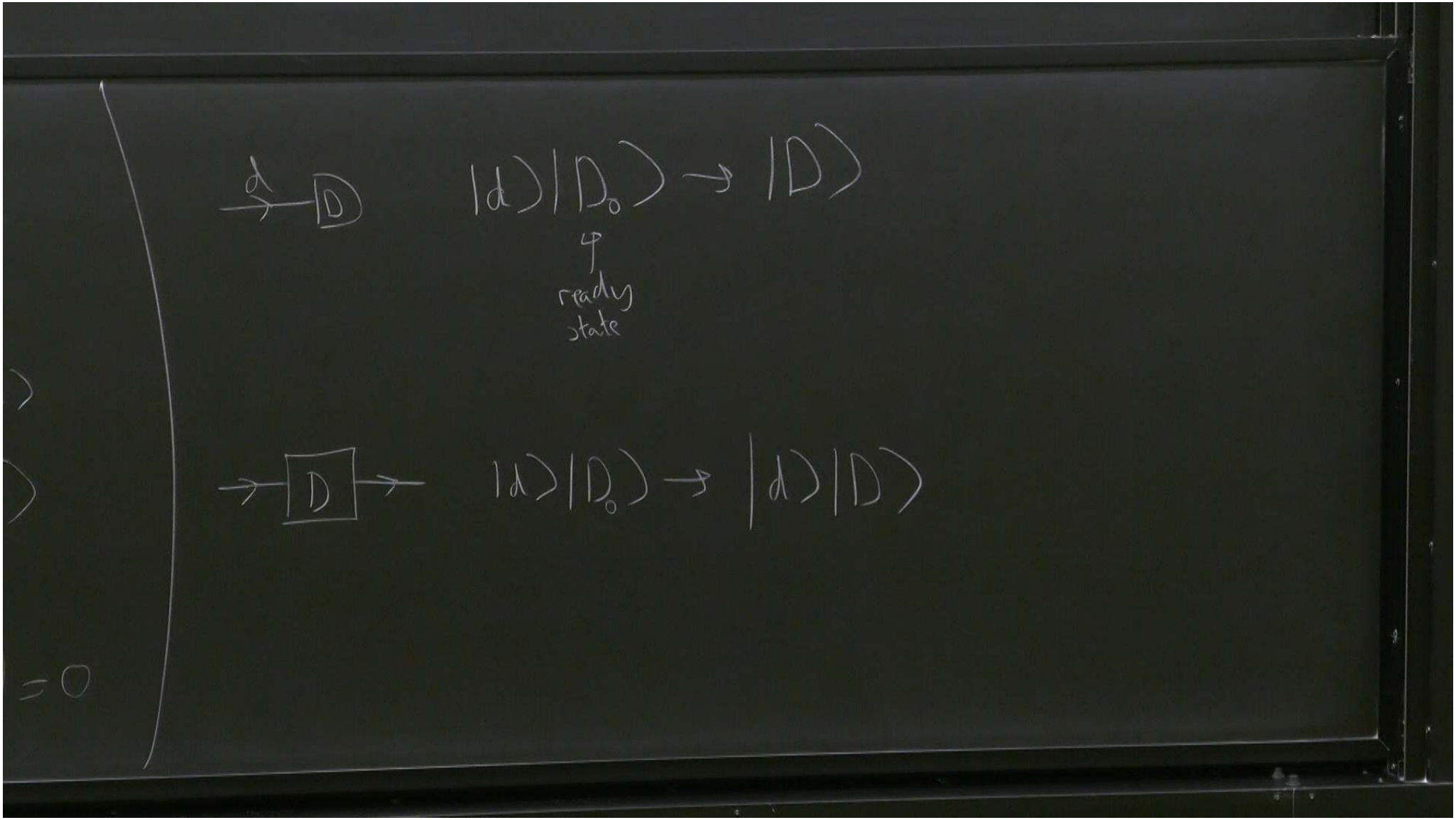
$\langle c|d\rangle = 0$

$\langle c|c\rangle = 1$

$\langle d|d\rangle = 1$

$\left(\sqrt{T}\langle c| - i\sqrt{R}\langle d|\right)\left(i\sqrt{R}|c\rangle + \sqrt{T}|d\rangle\right) = 0$

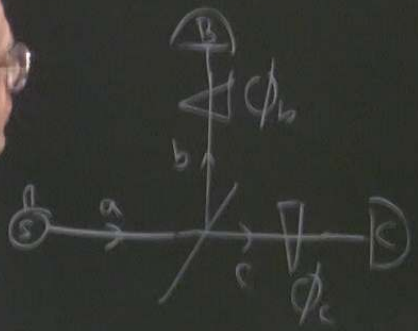

a
a
|a⟩ → i|a⟩
T+R=1
d
T,R
|a⟩ → √T|c⟩ + i√R|d⟩
a
c
|b⟩ → i√R|c⟩ + √T|d⟩
b
⟨c|d⟩ = 0
⟨c|c⟩ = 1
⟨d|d⟩ = 1
(√T⟨c| − i√R⟨d|)(i√R|c⟩ + √T|d⟩) = 0
d
D
|a⟩
|a⟩


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

Zero example

$$|a\rangle|A_0\rangle \to |A\rangle$$

First example



$$|a\rangle|B_0\rangle|C_0\rangle \to \left(\sqrt{R}\, e^{i\phi_b}|b\rangle + \sqrt{T}\, e^{i\phi_c}|c\rangle\right)|B_0\rangle|C_0\rangle$$

$$\to \sqrt{R}\, e^{i\phi_b}|B\rangle|C_0\rangle + \sqrt{T}\, e^{i\phi_c}|B_0\rangle|C\rangle$$

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

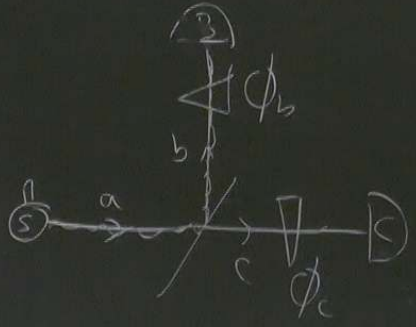
$$\text{prob}(B_0 C) = T$$

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

Zero example

$|a\rangle|A_0\rangle \rightarrow |A\rangle$

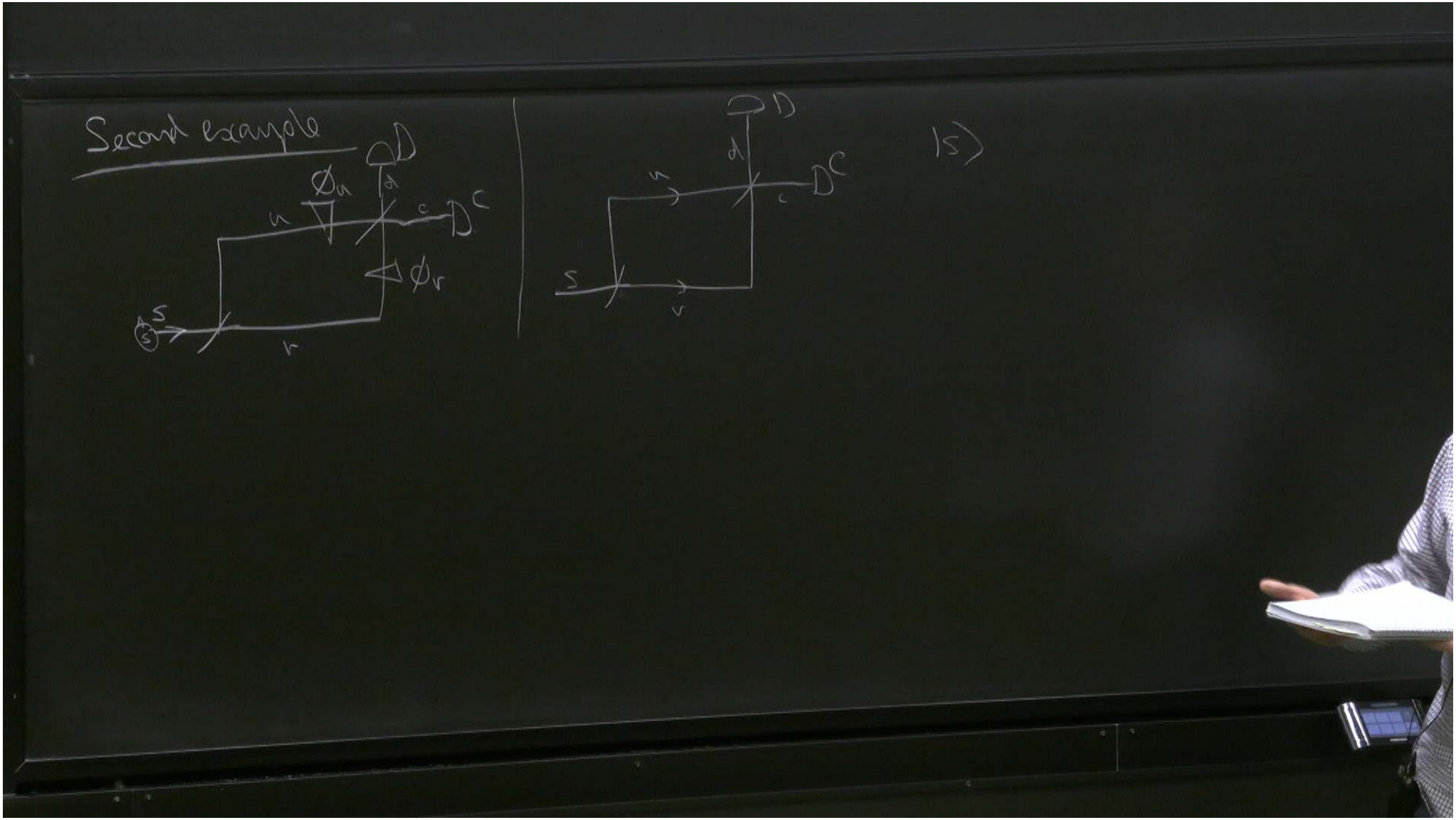
First example

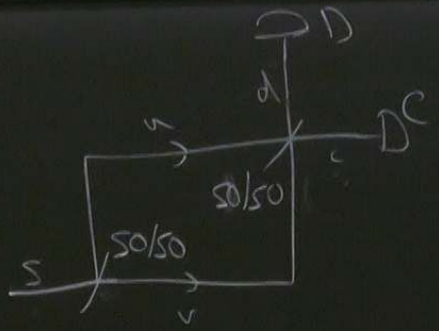


$|a\rangle|B_0\rangle|C_0\rangle \rightarrow \left(i\sqrt{R}\, e^{i\phi_b}|b\rangle + \sqrt{T}\, e^{i\phi_c}|c\rangle\right)|B_0\rangle|C_0\rangle$

$\rightarrow i\sqrt{R}\, e^{i\phi_b}|B\rangle|C_0\rangle + \sqrt{T}\, e^{i\phi_c}|B_0\rangle$

$|a\rangle \rightarrow |\bar{a}\rangle$

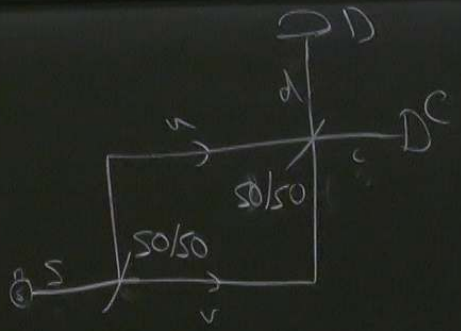

Second example
D
ϕ_u
u
d
c
C
ϕ_r
S
s
r
D
u
d
C
c
S
r
$|s\rangle$



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

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

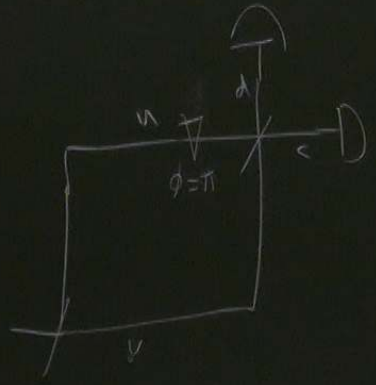
$$= i|c\rangle$$



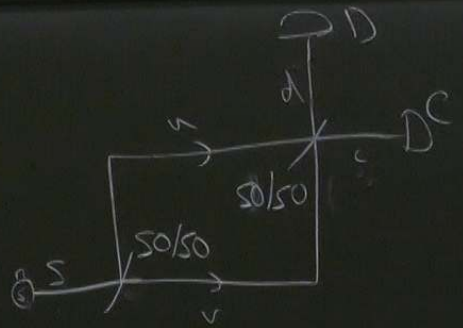
$$|s\rangle \rightarrow \frac{i}{\sqrt{2}}|u\rangle + \frac{1}{\sqrt{2}}|v\rangle$$

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

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



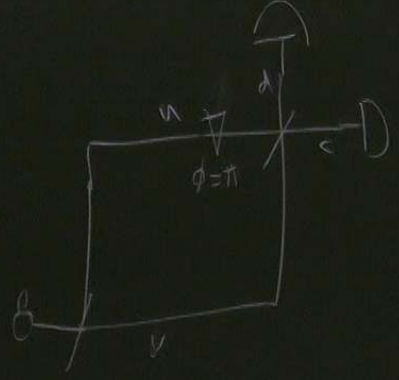
$|s\rangle \rightarrow \cdots\cdots \rightarrow |d\rangle$



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

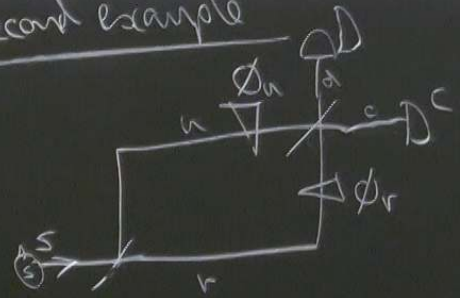
$$\rightarrow \frac{i}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|c\rangle + \frac{i}{\sqrt{2}}|d\rangle\right) + \frac{1}{\sqrt{2}}\left(\frac{i}{\sqrt{2}}|c\rangle + \frac{1}{\sqrt{2}}|d\rangle\right)$$

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

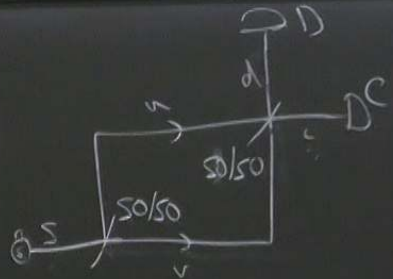


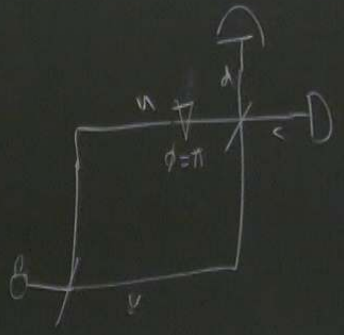
$|s\rangle + \cdots \rightarrow |d\rangle$ Detector D always fires

Second example



Mach Zehnder



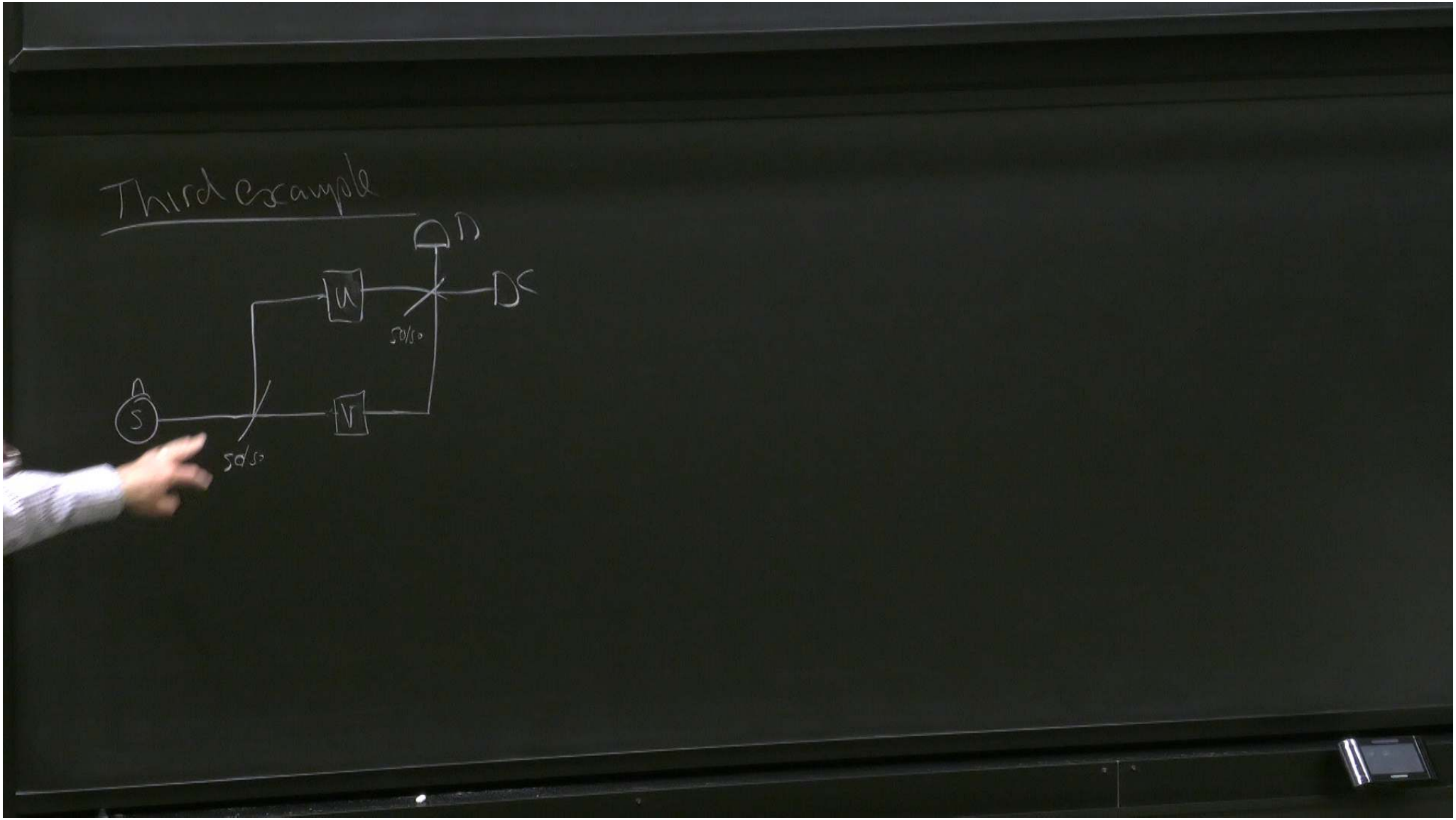


$$|s\rangle \rightarrow \frac{i}{\sqrt{2}}|u\rangle + \frac{1}{\sqrt{2}}|v\rangle$$

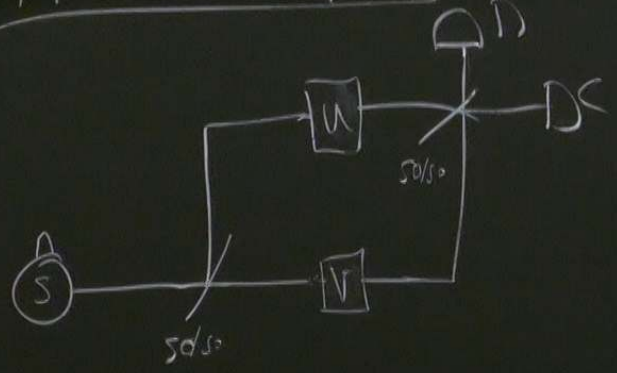
$$\rightarrow \frac{i}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|c\rangle + \frac{i}{\sqrt{2}}|d\rangle\right) + \frac{1}{\sqrt{2}}\left(\frac{i}{\sqrt{2}}|c\rangle + \frac{1}{\sqrt{2}}|d\rangle\right)$$

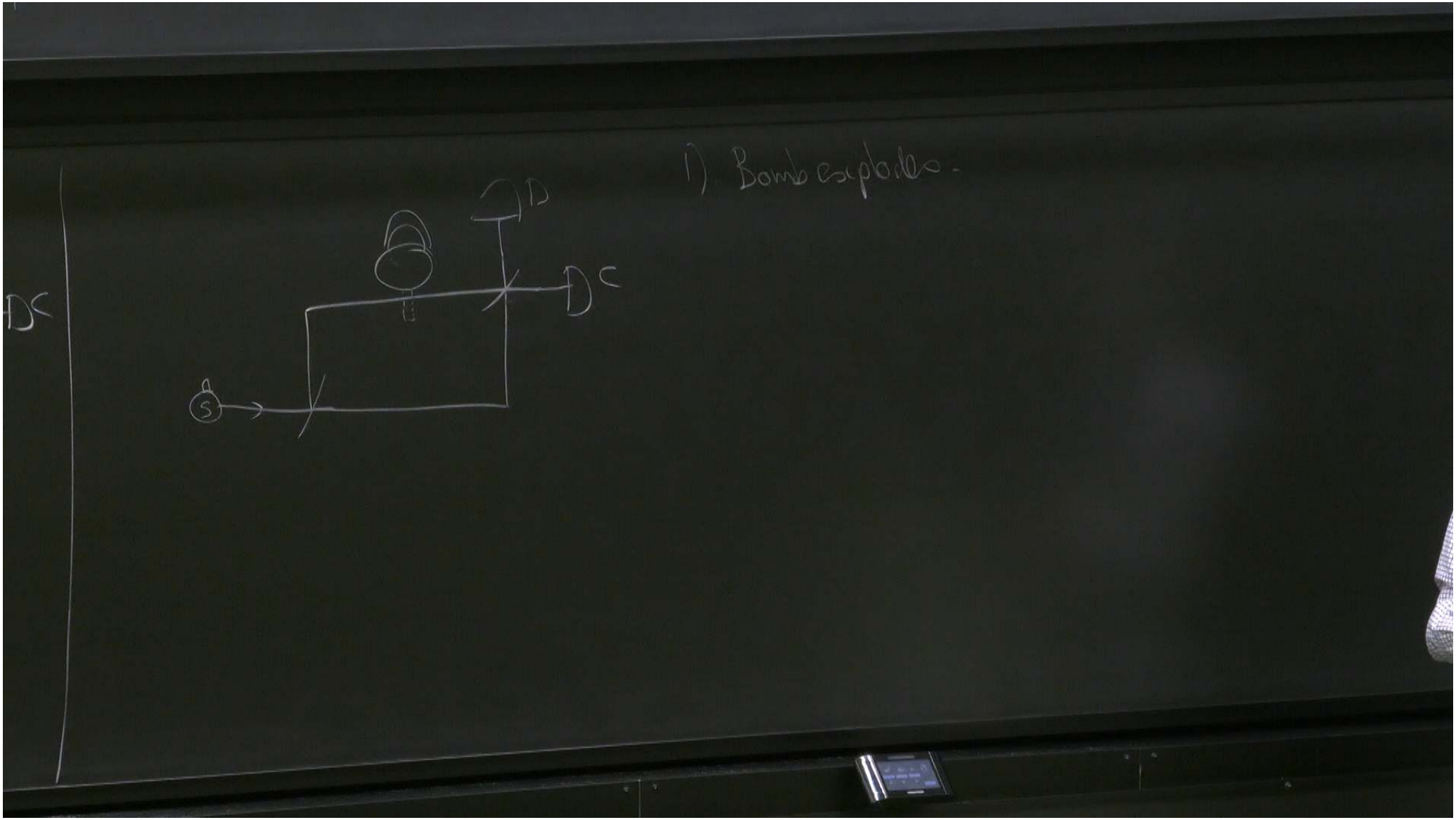
$= i|c\rangle$ Detector C always fires.

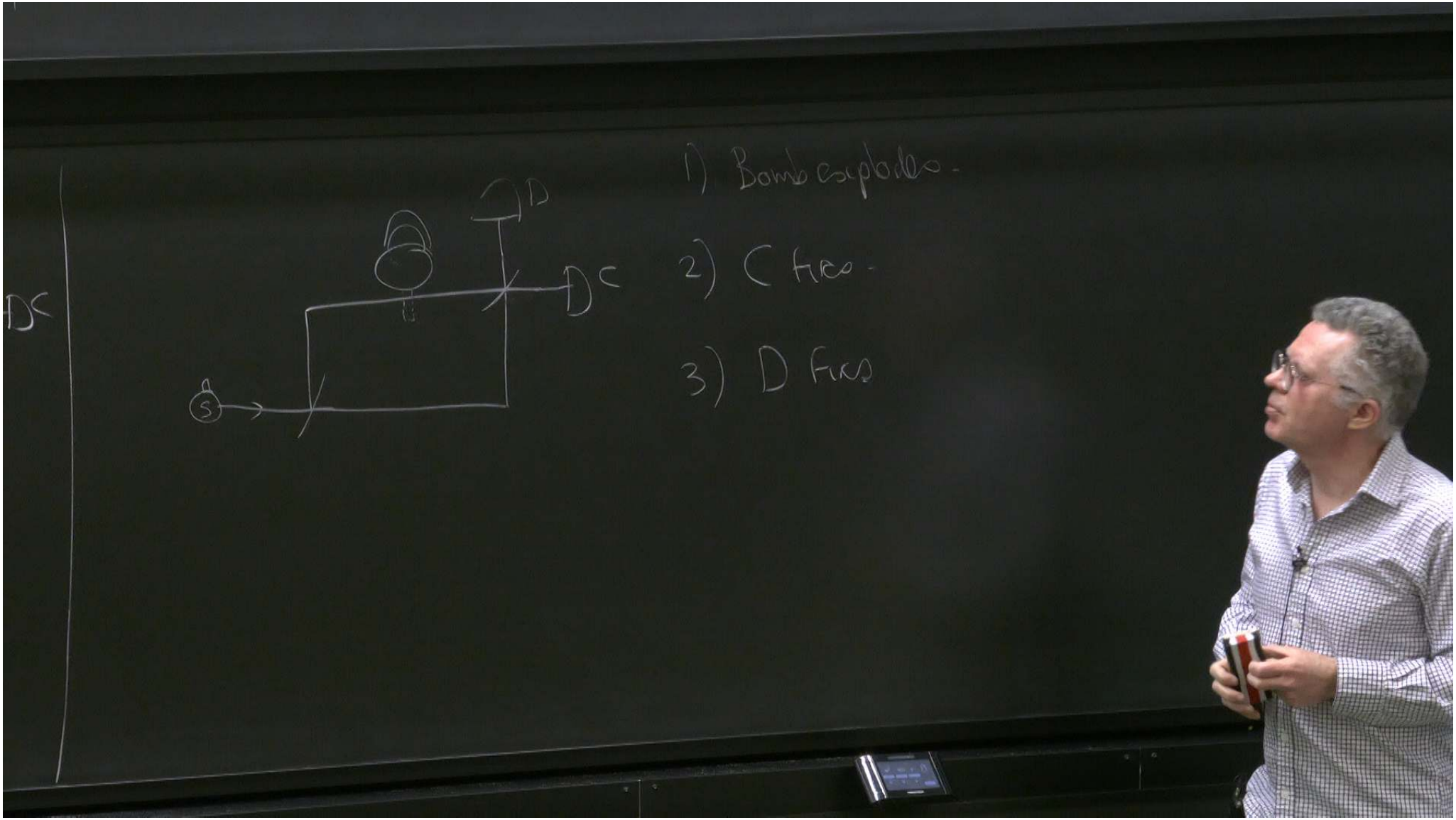
$|s\rangle \rightarrow \cdots \rightarrow |d\rangle$ Detector D always fires

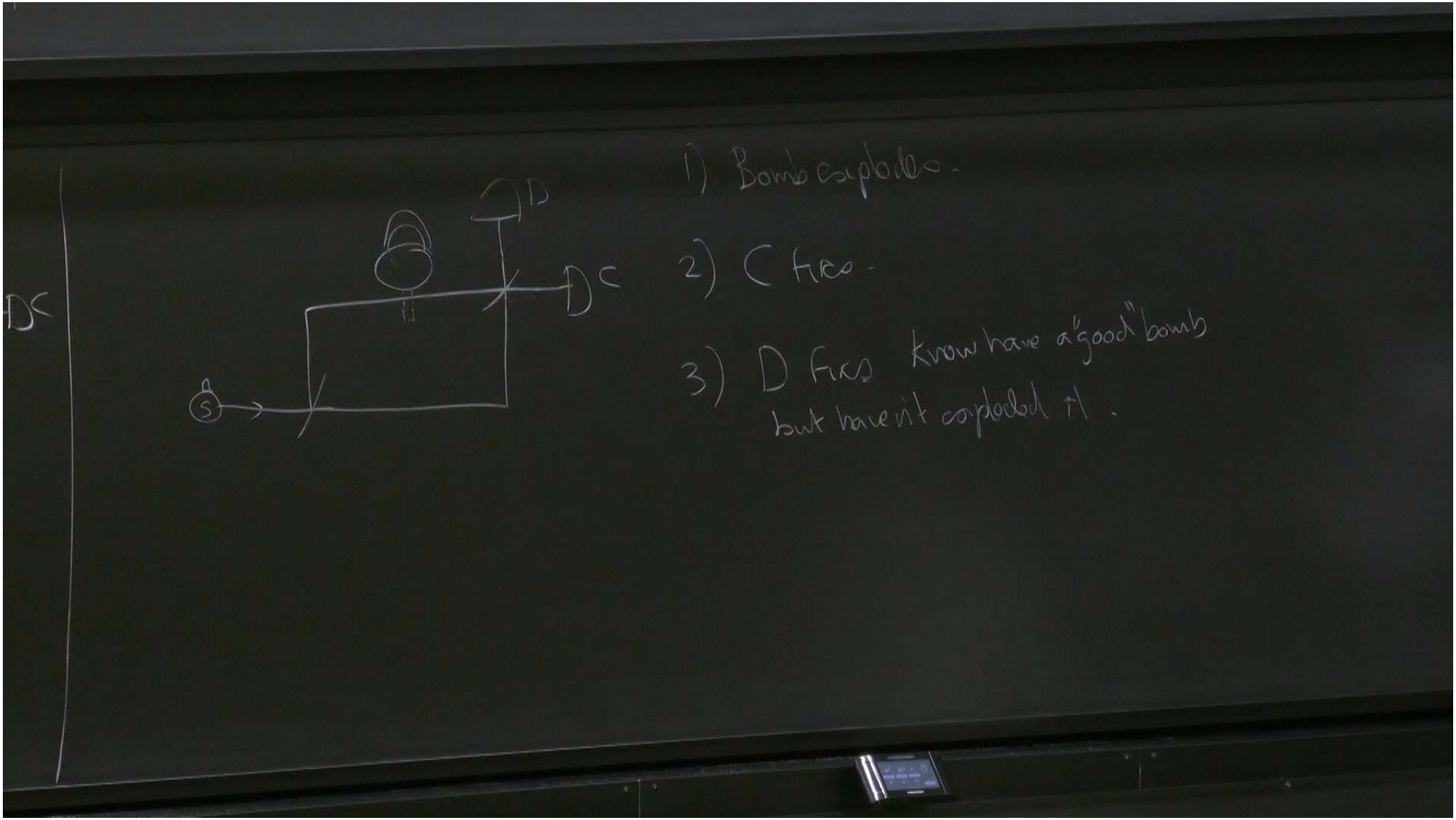

Third example
D
W
DC
50/50
S
V
50/50

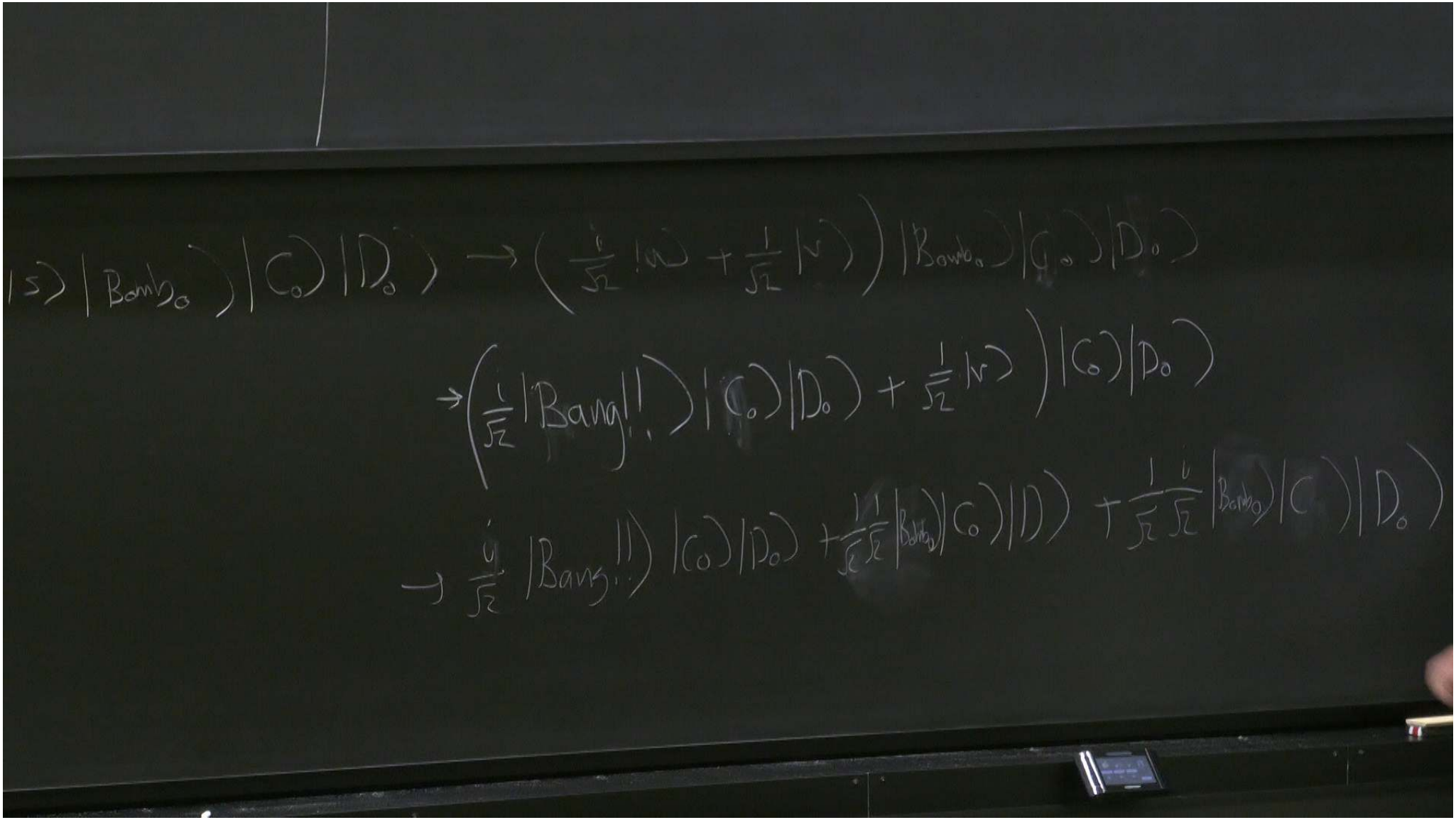
Third example

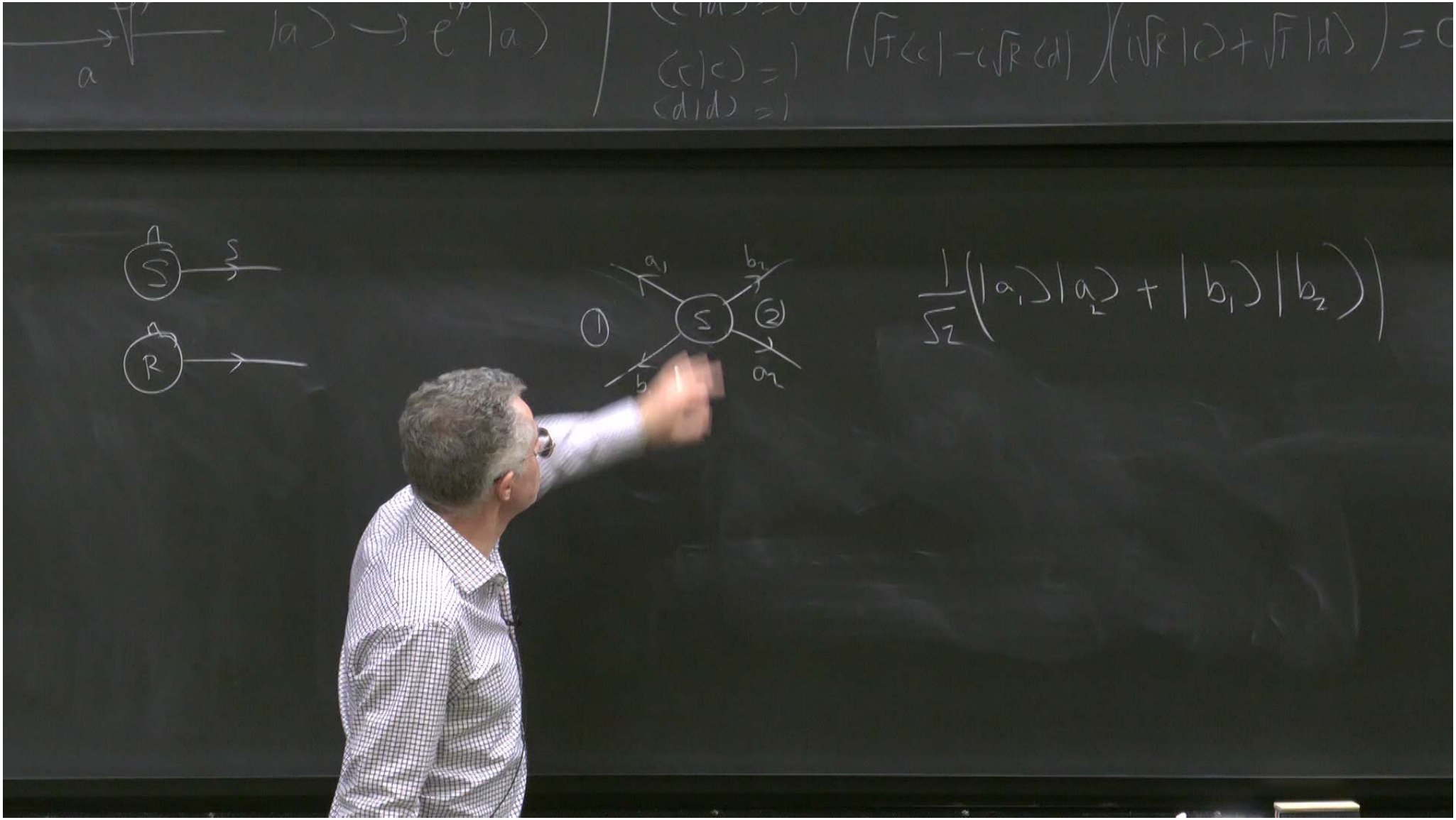


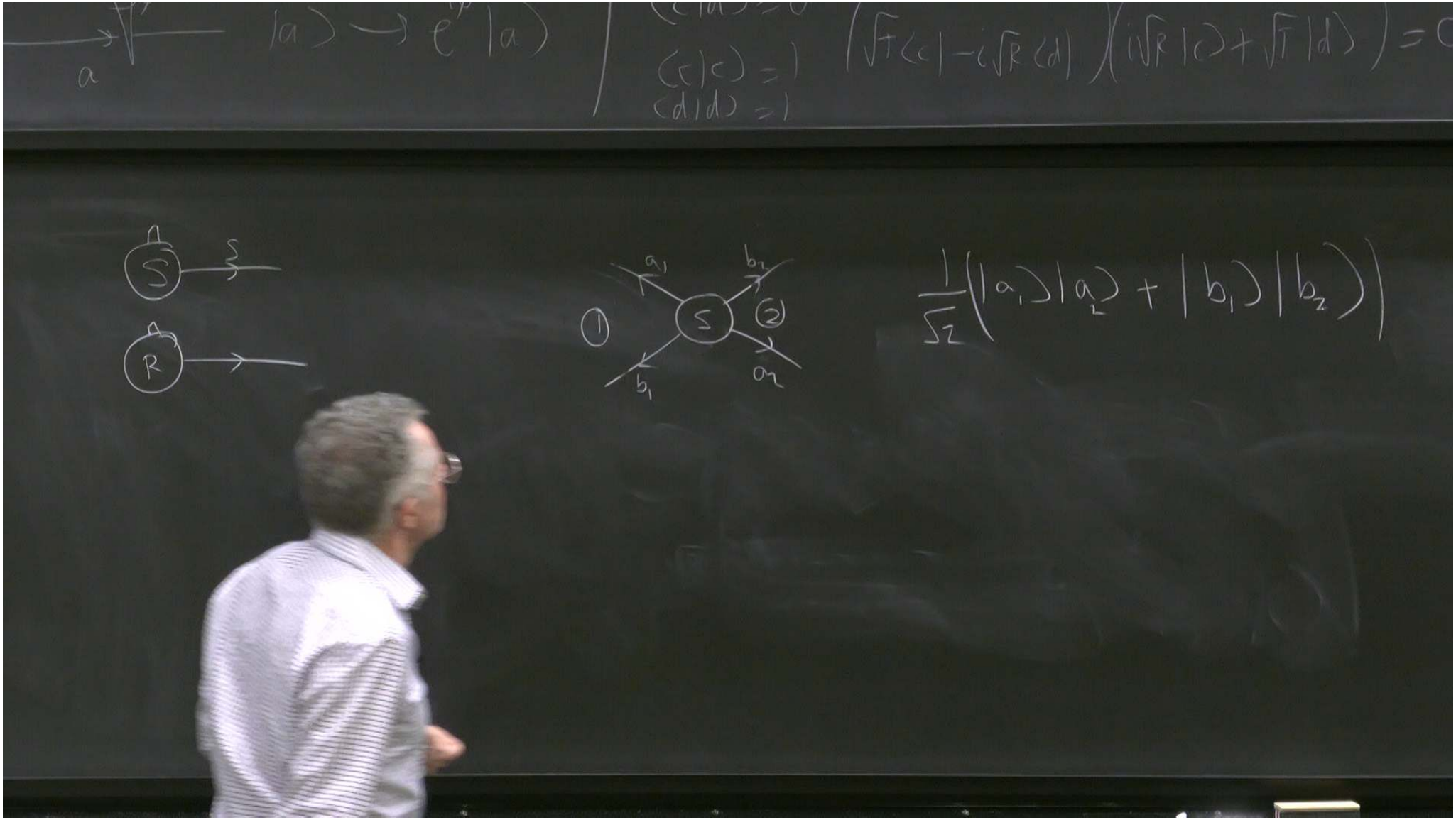

1) Bomb explodes.
DC
DC
S

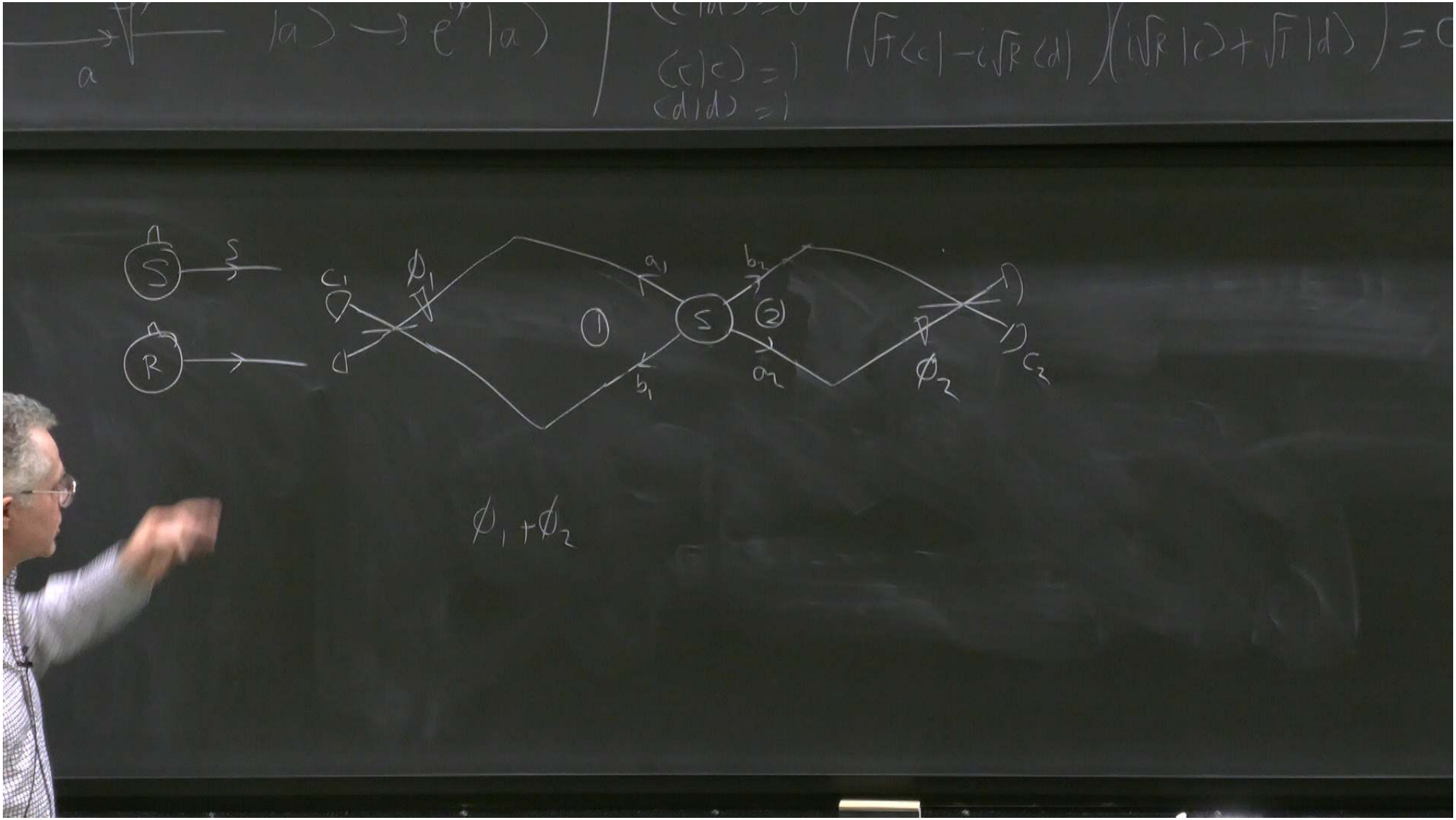

1) Bomb explodes.
2) C fires.
3) D fires
D
D
C
S

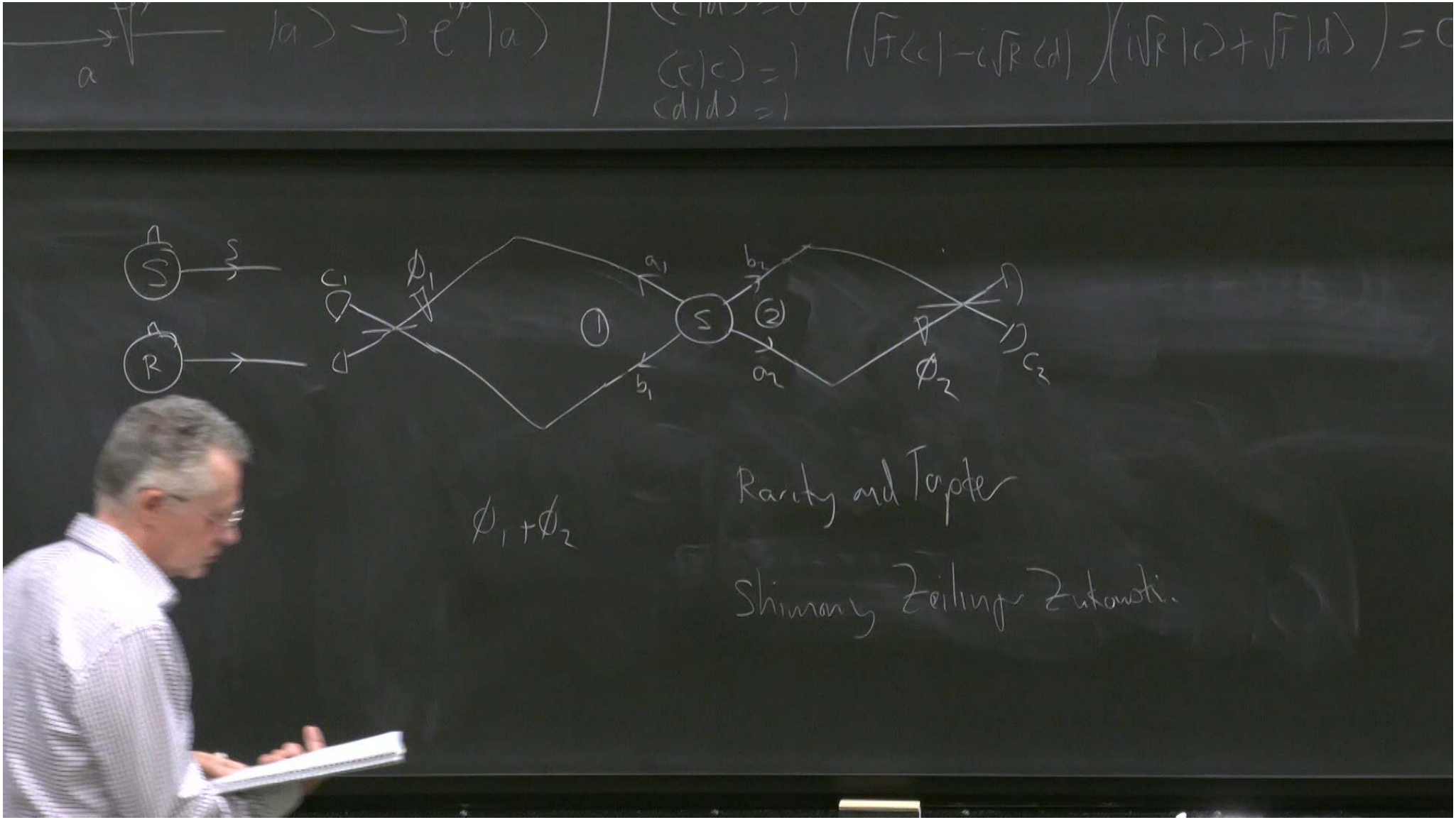

DC
D
DC
S
1) Bomb explodes.
2) C fires.
3) D fires knowing have a "good" bomb
but have it exploded it.


|S⟩|Bomb₀⟩|C₀⟩|D₀⟩ → (1/√2 |↑⟩ + 1/√2 |↓⟩)|Bomb₀⟩|C₀⟩|D₀⟩
→ (1/√2 |Bang!!⟩|C₀⟩|D₀⟩ + 1/√2 |↓⟩)|C₀⟩|D₀⟩
→ 1/√2 |Bang!!⟩|C₀⟩|D₀⟩ + 1/√2 1/√2 |Bomb₀⟩|C₀⟩|D₀⟩ + 1/√2 1/√2 |Bomb₀⟩|C₀⟩|D₀⟩


S
R
S
1
2
a_1
b_2
b_1
a_2
$\frac{1}{\sqrt{2}}\left(|a_1\rangle|a_2\rangle + |b_1\rangle|b_2\rangle\right)$


S
R
S
a1
b2
1
S
2
b1
a2
$\frac{1}{\sqrt{2}}\left(|a_1\rangle|a_2\rangle + |b_1\rangle|b_2\rangle\right)$


S
R
S
R
ϕ_1
ϕ_2
a_1
b_2
b_1
a_2
c_2
1
S
2
$\phi_1 + \phi_2$


S
R
ϕ_1
ϕ_2
a_1
b_1
a_2
b_2
c_2
$\phi_1 + \phi_2$
Rarity and Tapster
Shimony Zeilinger Zukowski