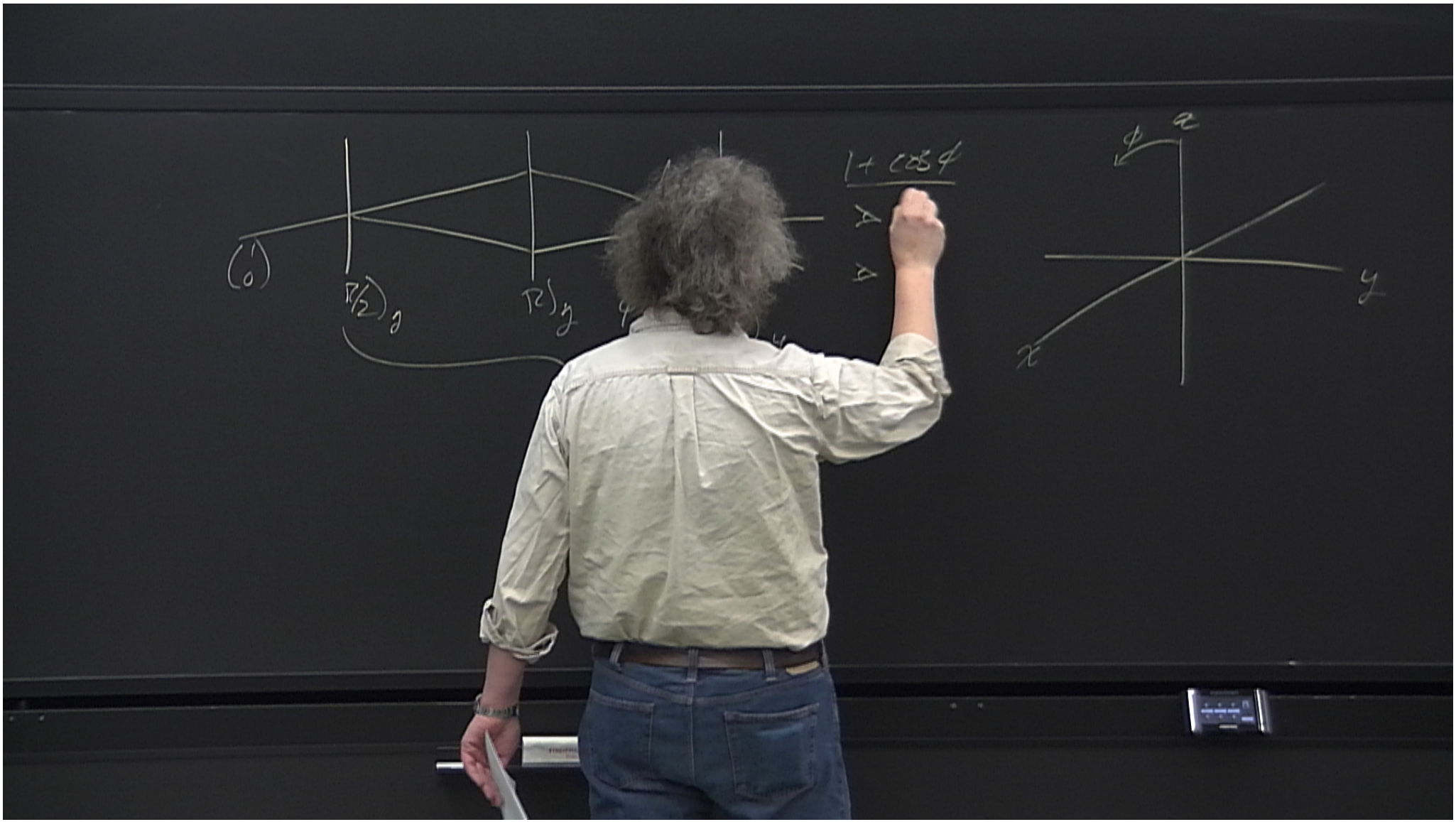
Title: 12/13 PSI - Explorations on Quantum Information Lecture 3

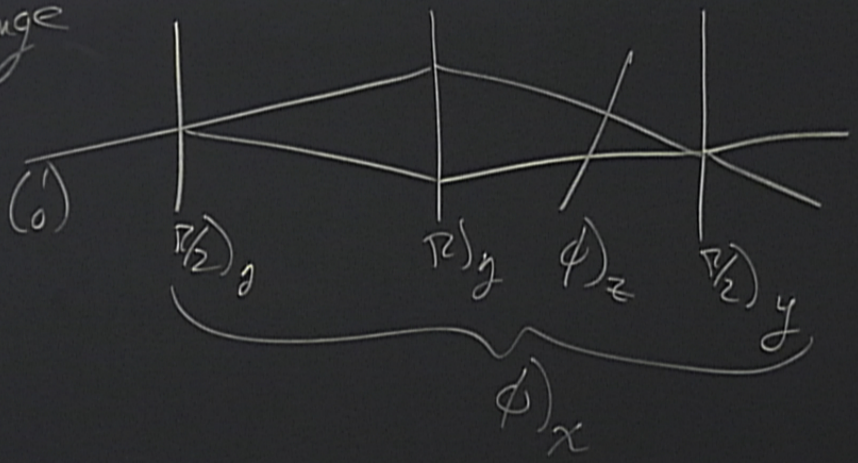
Date: Mar 20, 2013 09:00 AM

URL: http://pirsa.org/13030056

Abstract:

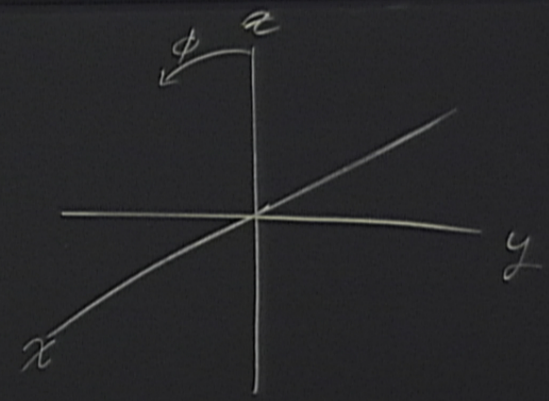

1+ cos φ
φ
x
y

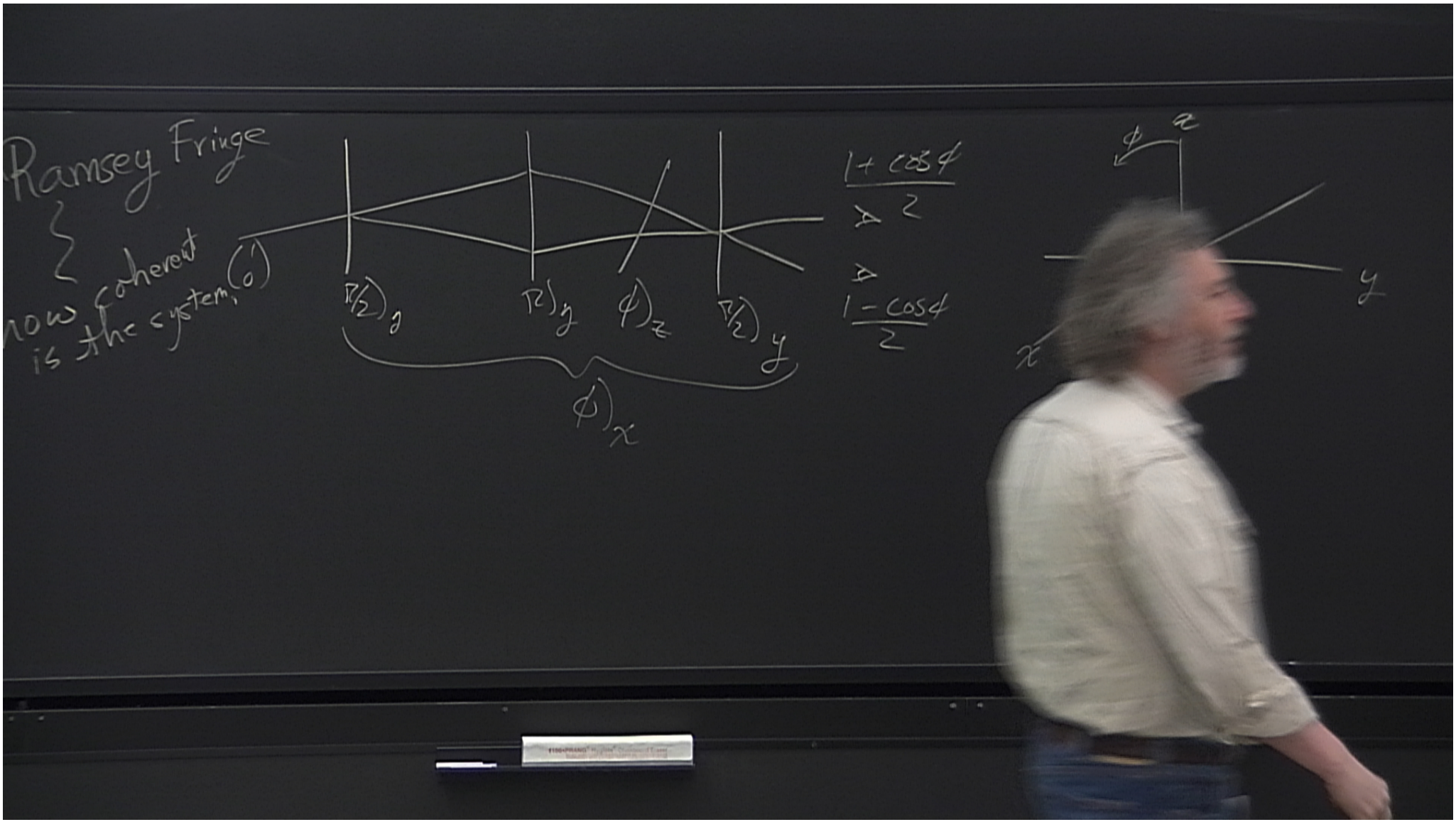
Ramsey Fringe

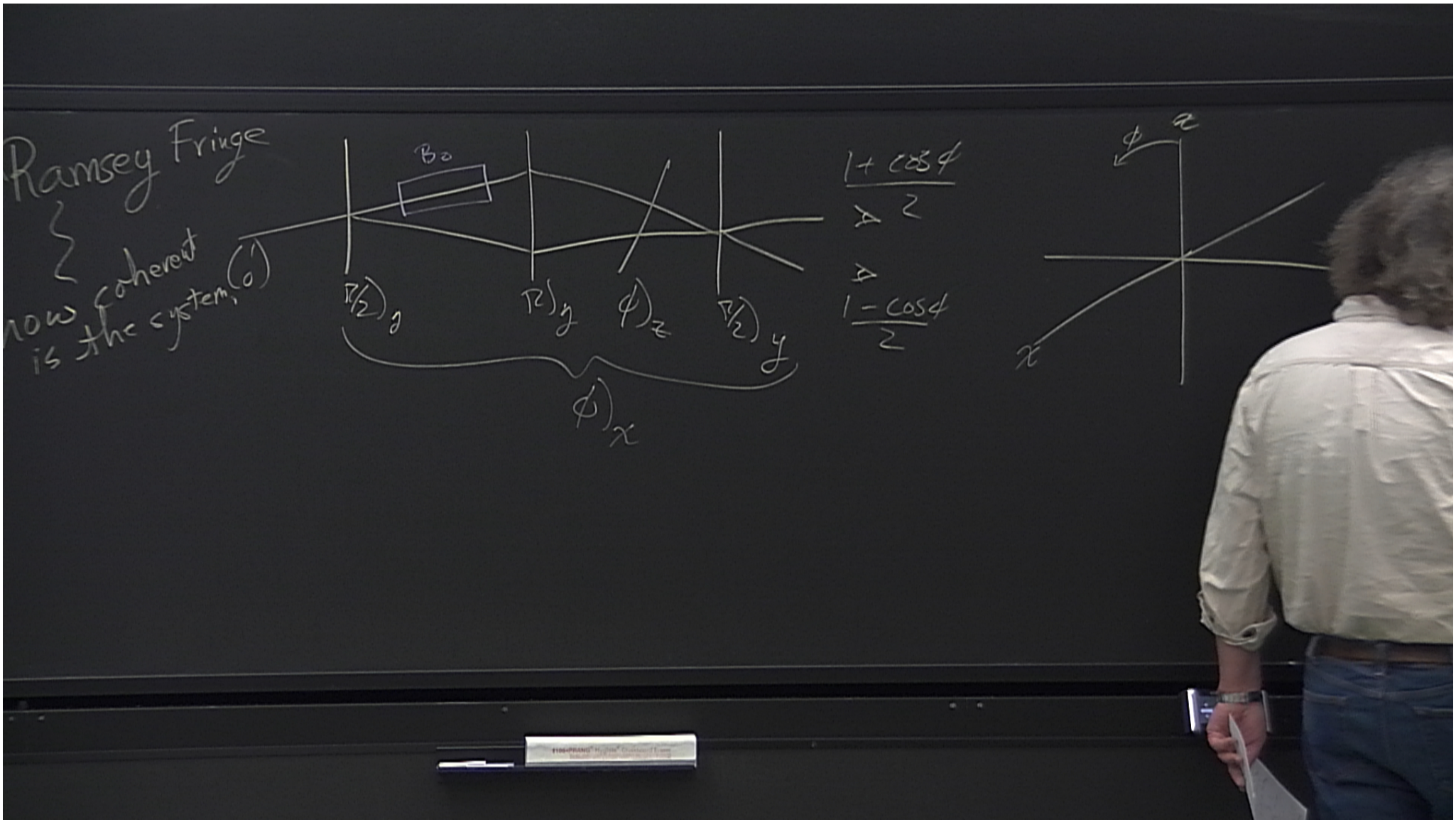


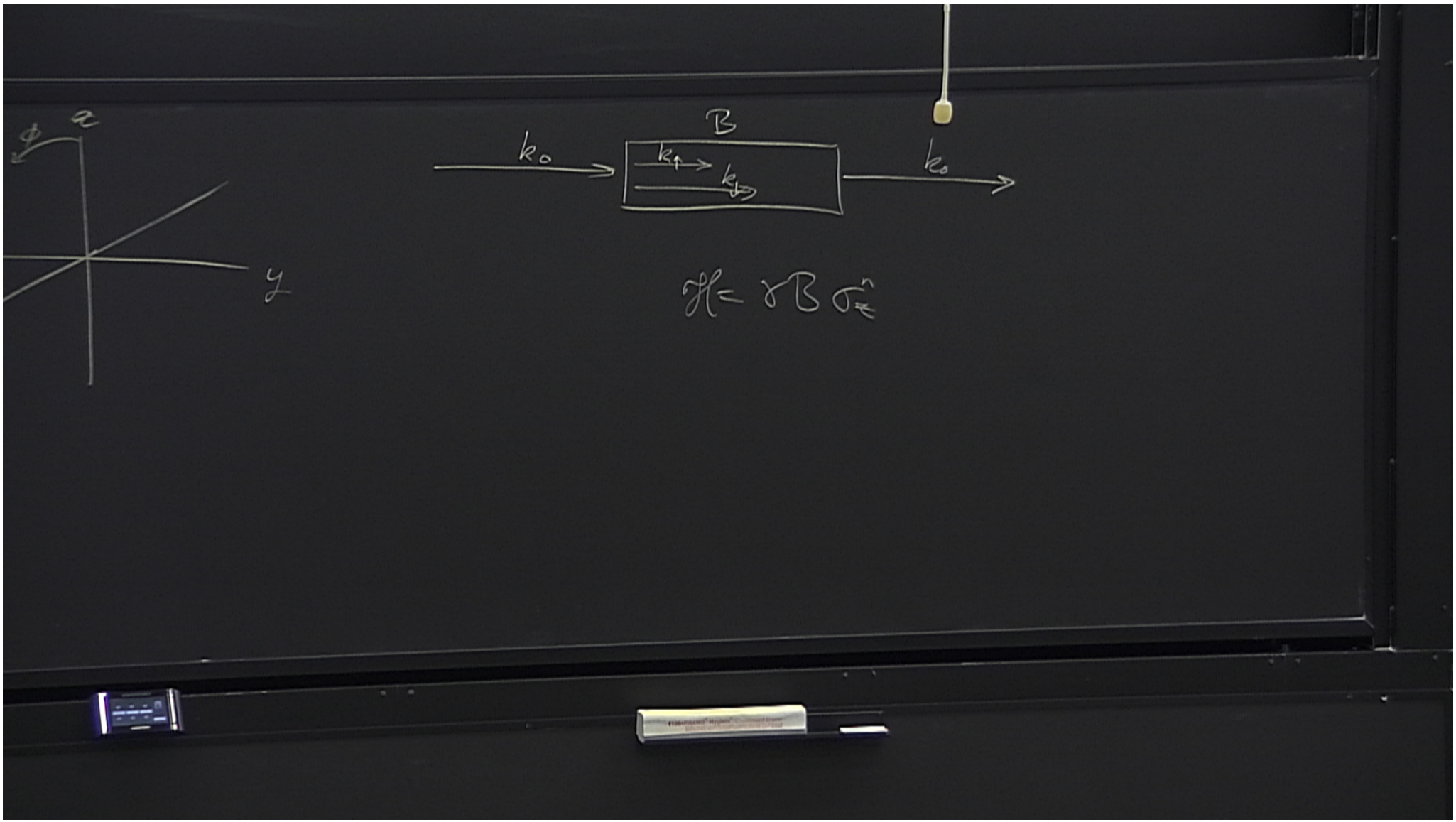
$$\frac{1+\cos\phi}{2}$$

$$\frac{1-\cos\phi}{2}$$



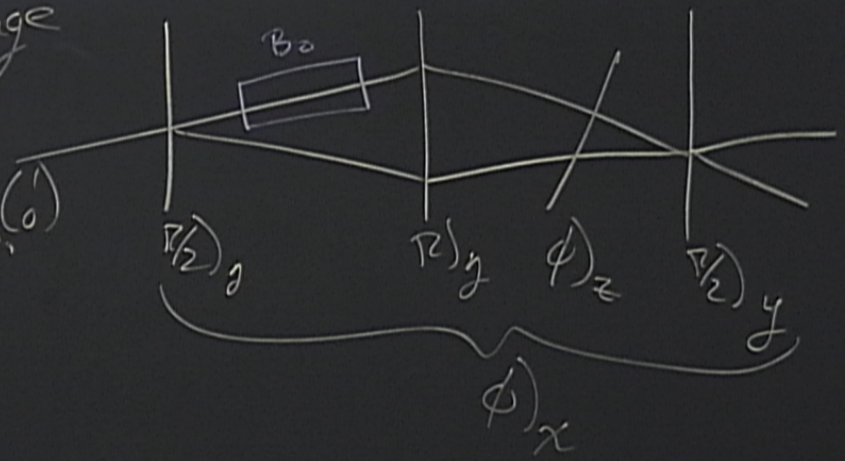

Ramsey Fringe
how coherent is the system?
π/2)x
π)y
φ)z
π/2)y
φ)x
1+cos φ / 2
1−cos φ / 2
φ
z
y
x


Ramsey Fringe
how coherent is the system?
B_0
$\pi/2)_y$
$\pi)_y$
$\phi)_z$
$\pi/2)_y$
$\phi)_x$
$\frac{1+\cos\phi}{2}$
$\frac{1-\cos\phi}{2}$
ϕ
z
x


ϕ
z
y
k_0
B
$k_\uparrow$
$k_\downarrow$
k_0
$\mathcal{H} = \gamma B \sigma_z$

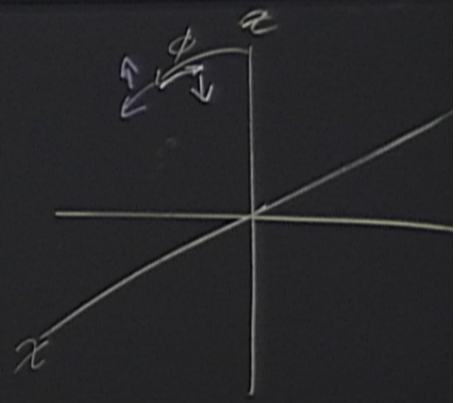
Ramsey Fringe

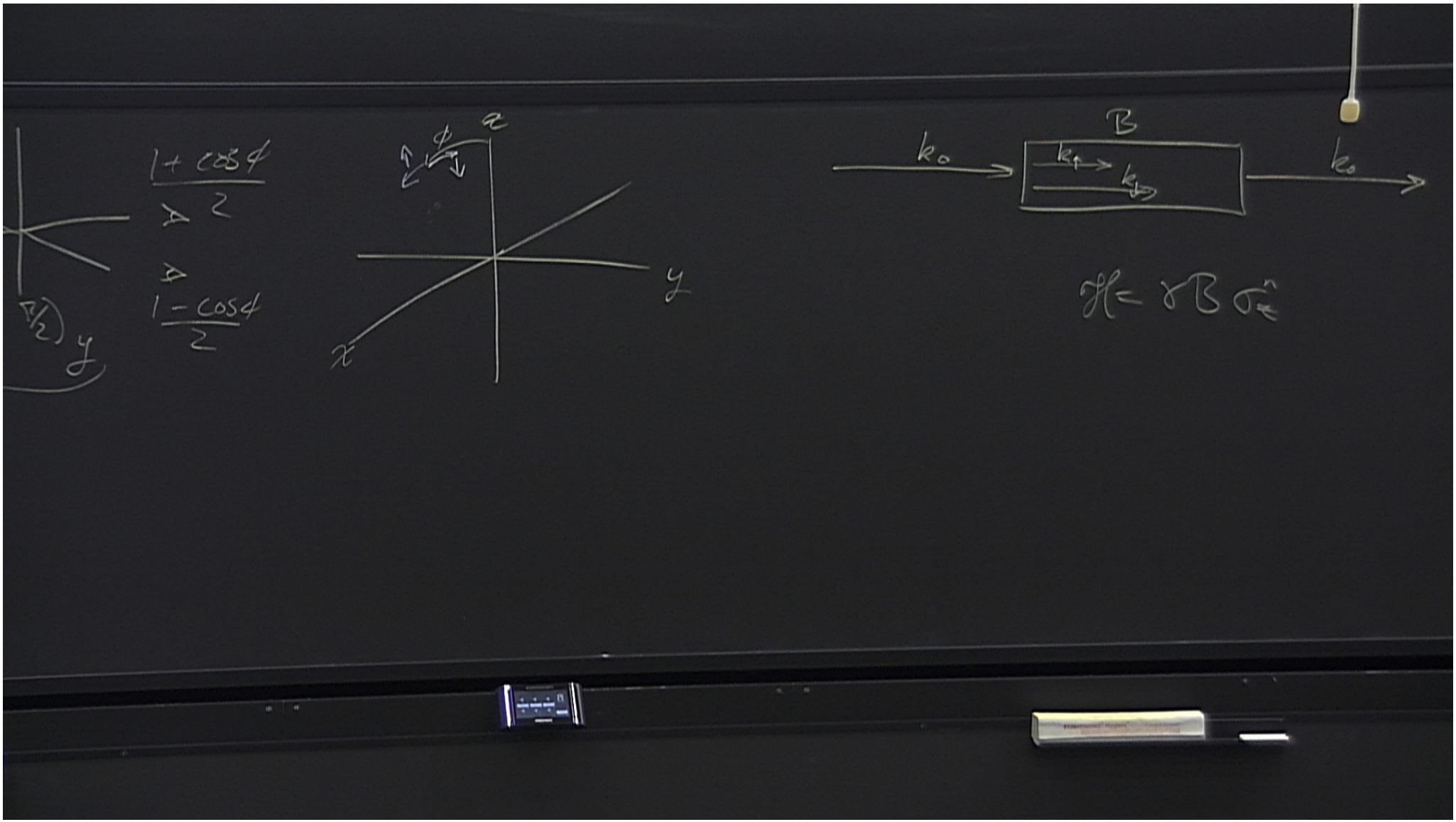
how coherent is the system?



$$\frac{1+\cos\phi}{2}$$

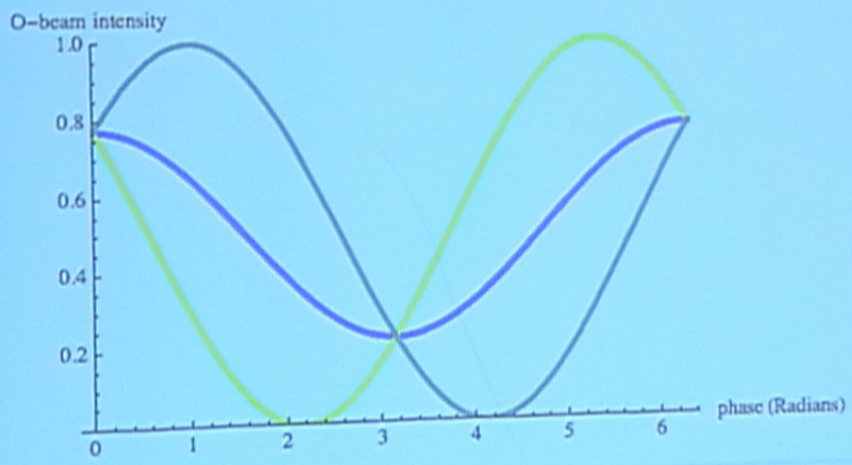
$$\frac{1-\cos\phi}{2}$$




$\frac{1+\cos\phi}{2}$
$\frac{1-\cos\phi}{2}$
$\pi/2$
y
ϕ
z
x
y
k_0
B
$k_\uparrow$
$k_\downarrow$
k_0
$\mathcal{H} = \gamma B \sigma_z$

```
Plot[M5Oup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
   PlotStyle → {RGBColor[0, 1, 0], Thickness[0.01]}, PlotRange → {0, 1}}],
 Plot[M5Odown[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
   PlotStyle → {RGBColor[0, .5, .5], Thickness[0.01]}, PlotRange → {0, 1}}]],
{b, 0, 2 π}, SaveDefinitions → True]
```

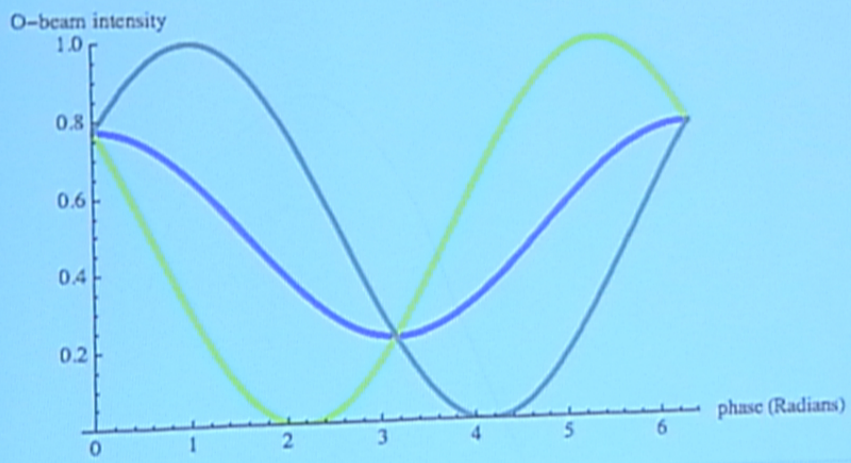
b




```
Manipulate[Show[
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "H-beam intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5Hup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
```

```
Plot[M5Oup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
   PlotStyle → {RGBColor[0, 1, 0], Thickness[0.01]}, PlotRange → {0, 1}}],
 Plot[M5Odown[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
   PlotStyle → {RGBColor[0, .5, .5], Thickness[0.01]}, PlotRange → {0, 1}}]],
{b, 0, 2 π}, SaveDefinitions → True]
```

b

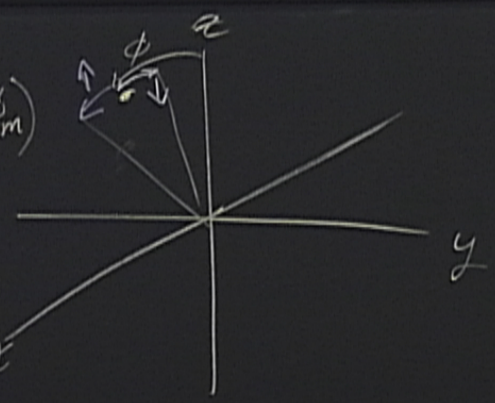


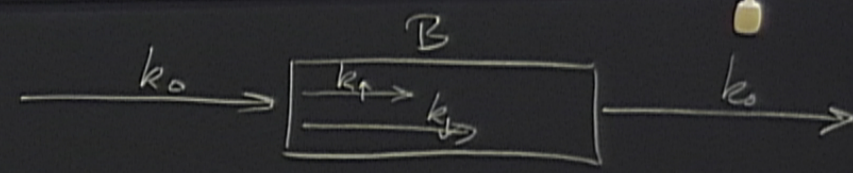

```
Manipulate[Show[
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "H-beam intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5Hup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
```

$$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$$

$$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$$

amplitude modulation

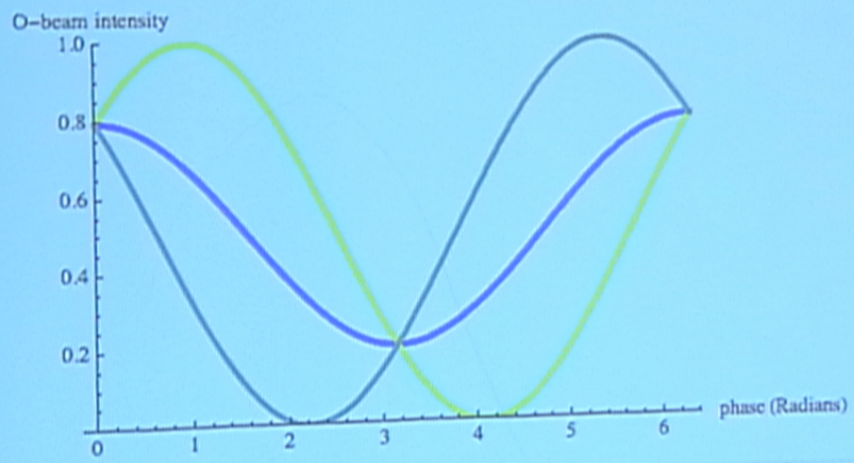




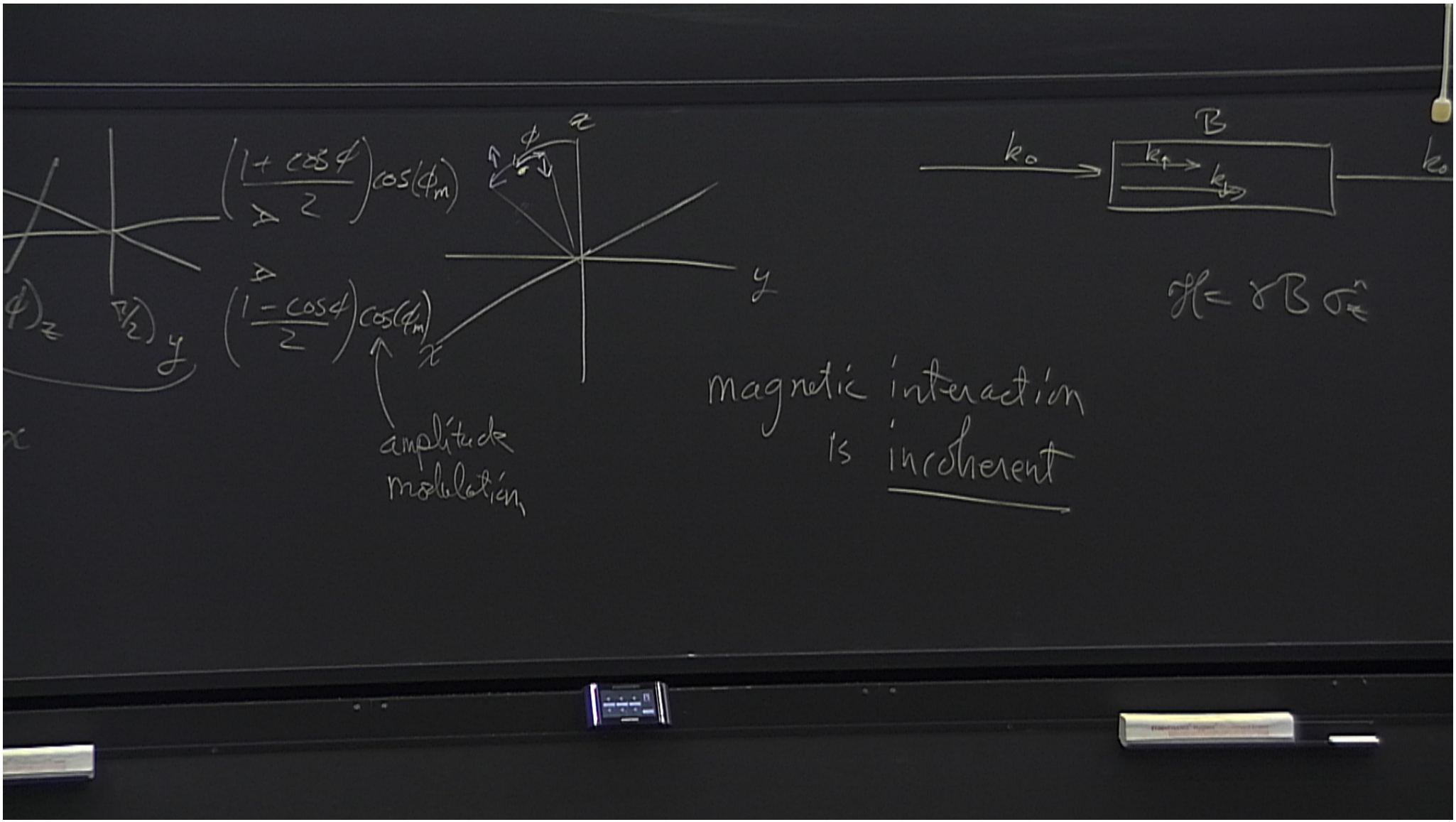
$$\mathcal{H} = \gamma B \sigma_z$$

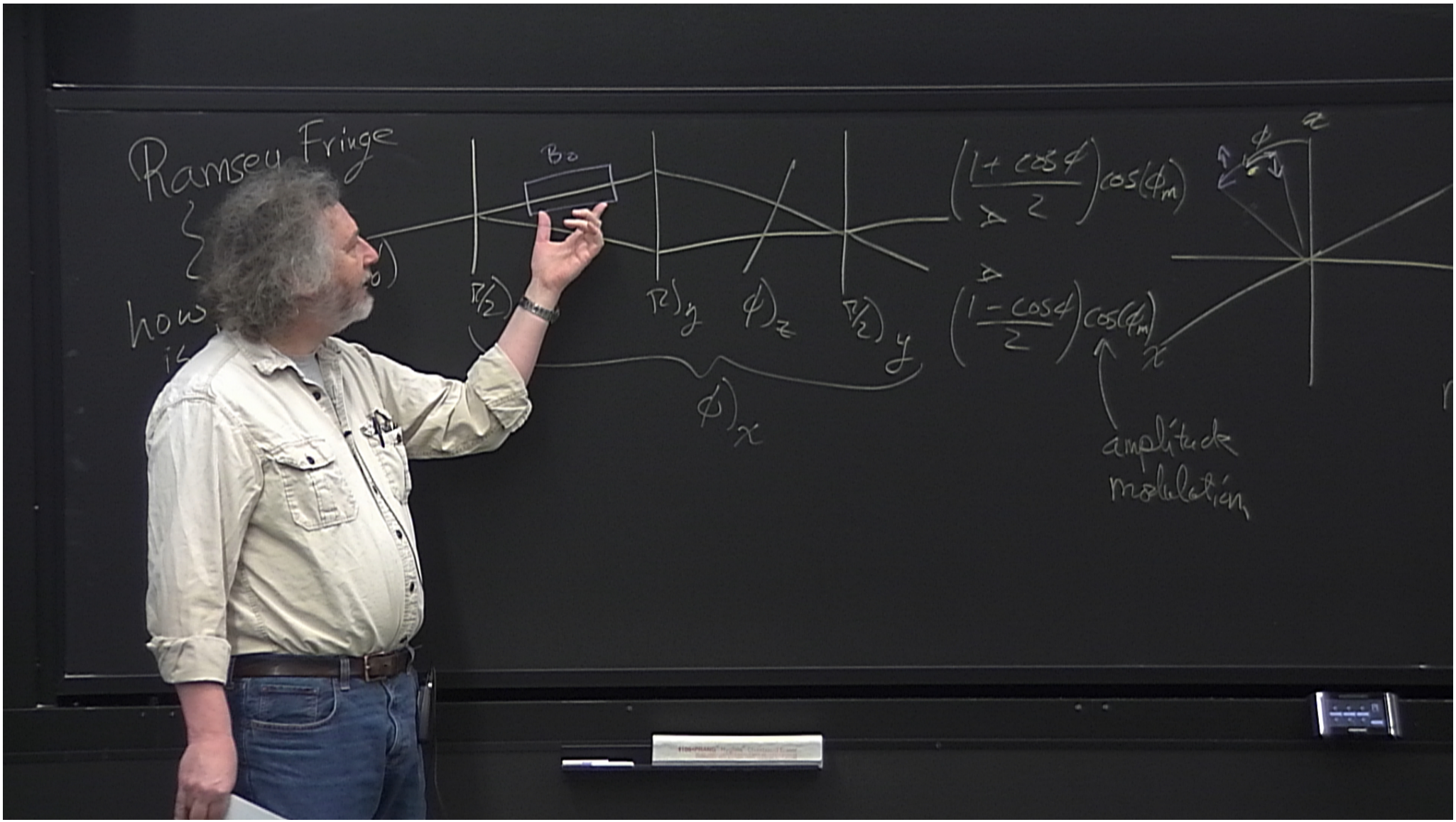
```
Plot[M5Oup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
   PlotStyle → {RGBColor[0, 1, 0], Thickness[0.01]}, PlotRange → {0, 1}}],
 Plot[M5Odown[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
   PlotStyle → {RGBColor[0, .5, .5], Thickness[0.01]}, PlotRange → {0, 1}}]],
{b, 0, 2 π}, SaveDefinitions → True]
```

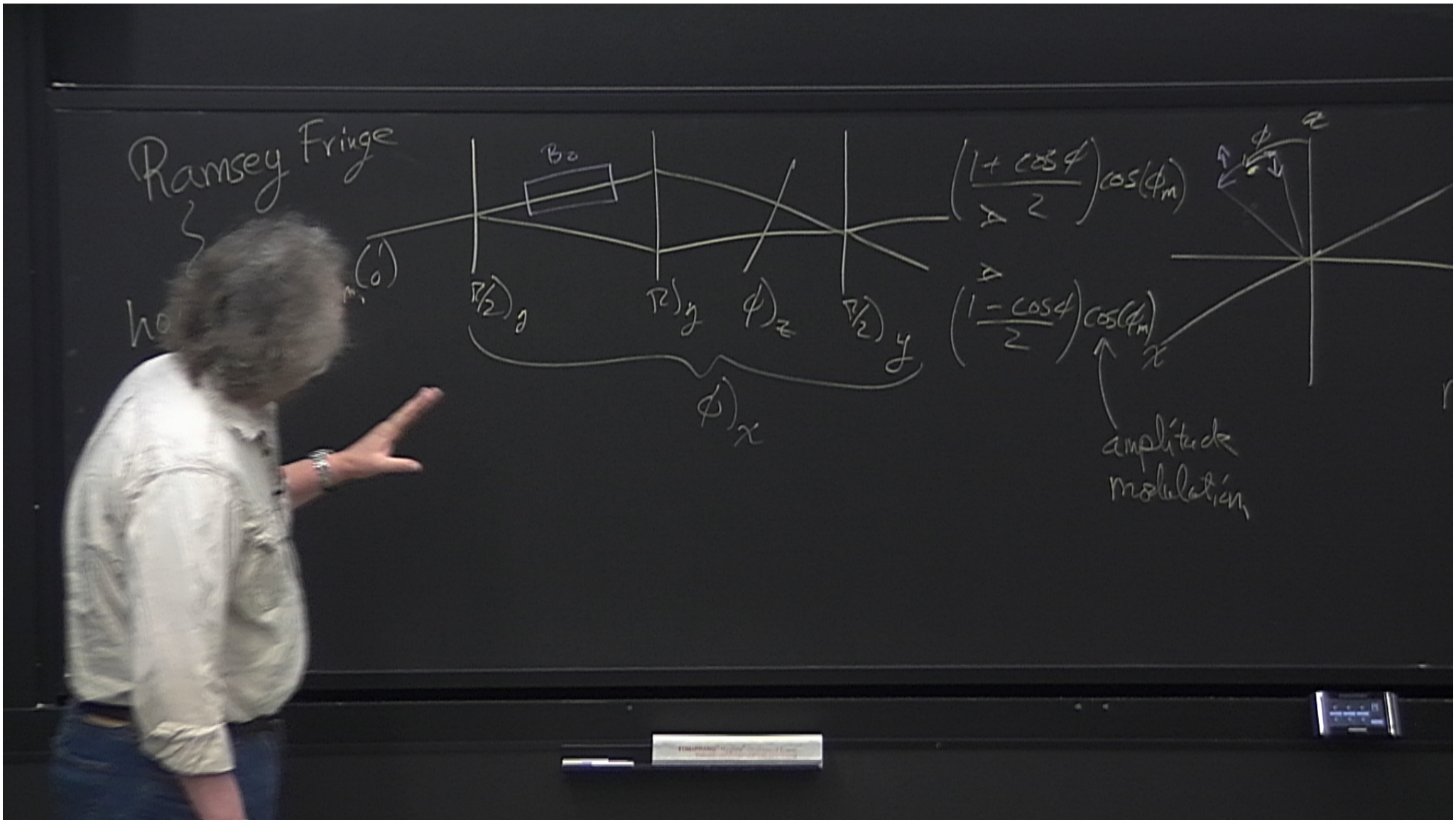
b

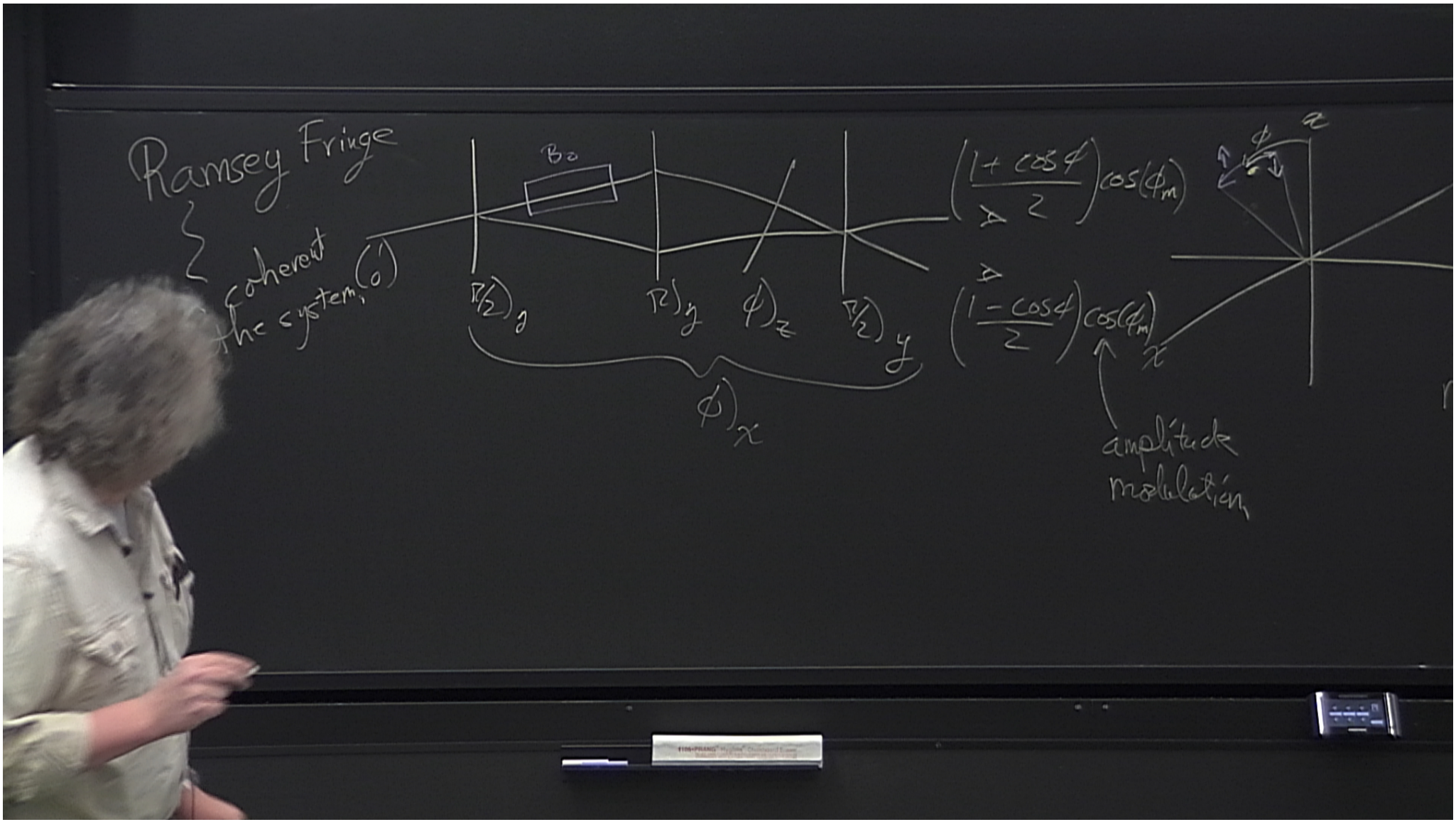



```
Manipulate[Show[
  Plot[M5H[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "H-beam intensity"},
    PlotStyle → {RGBColor[0, 0, 1], Thickness[0.01]}, PlotRange → {0, 1}}],
  Plot[M5Hup[a, b], {a, 0, 2 π}, {AxesLabel → {"phase (Radians)", "intensity"},
```


$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$
$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$
amplitude modulation
magnetic interaction is incoherent
k_0
B
$\mathcal{H} = \gamma B \sigma_z$

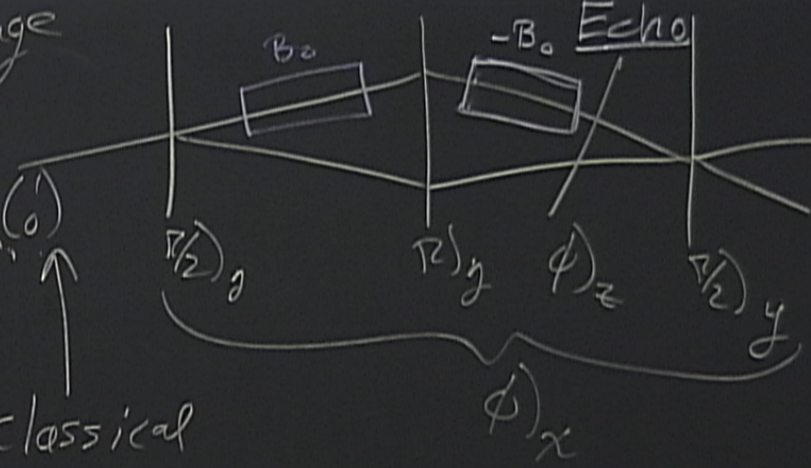

Ramsey Fringe
B0
π/2
π)y
φ)z
π/2)y
φ)x
(1+cosφ/2) cos(φm)
(1−cosφ/2) cos(φm)
amplitude modulation
x
z
φ


Ramsey Fringe
B_0
$\pi/2)_y$
$\pi)_y$
$\phi)_z$
$\pi/2)_y$
$\phi)_x$
$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$
$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$
amplitude modulation
z
x


Ramsey Fringe
coherent
the system
B_0
$\pi/2)_y$
$\pi)_y$
$\phi)_z$
$\pi/2)_y$
$\phi)_x$
$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$
$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$
amplitude
modulation
ϕ
z
x

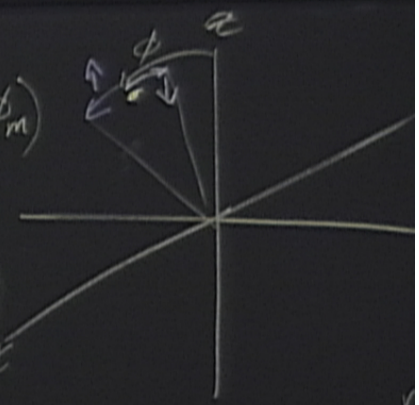
Ramsey Fringe

how coherent is the system?



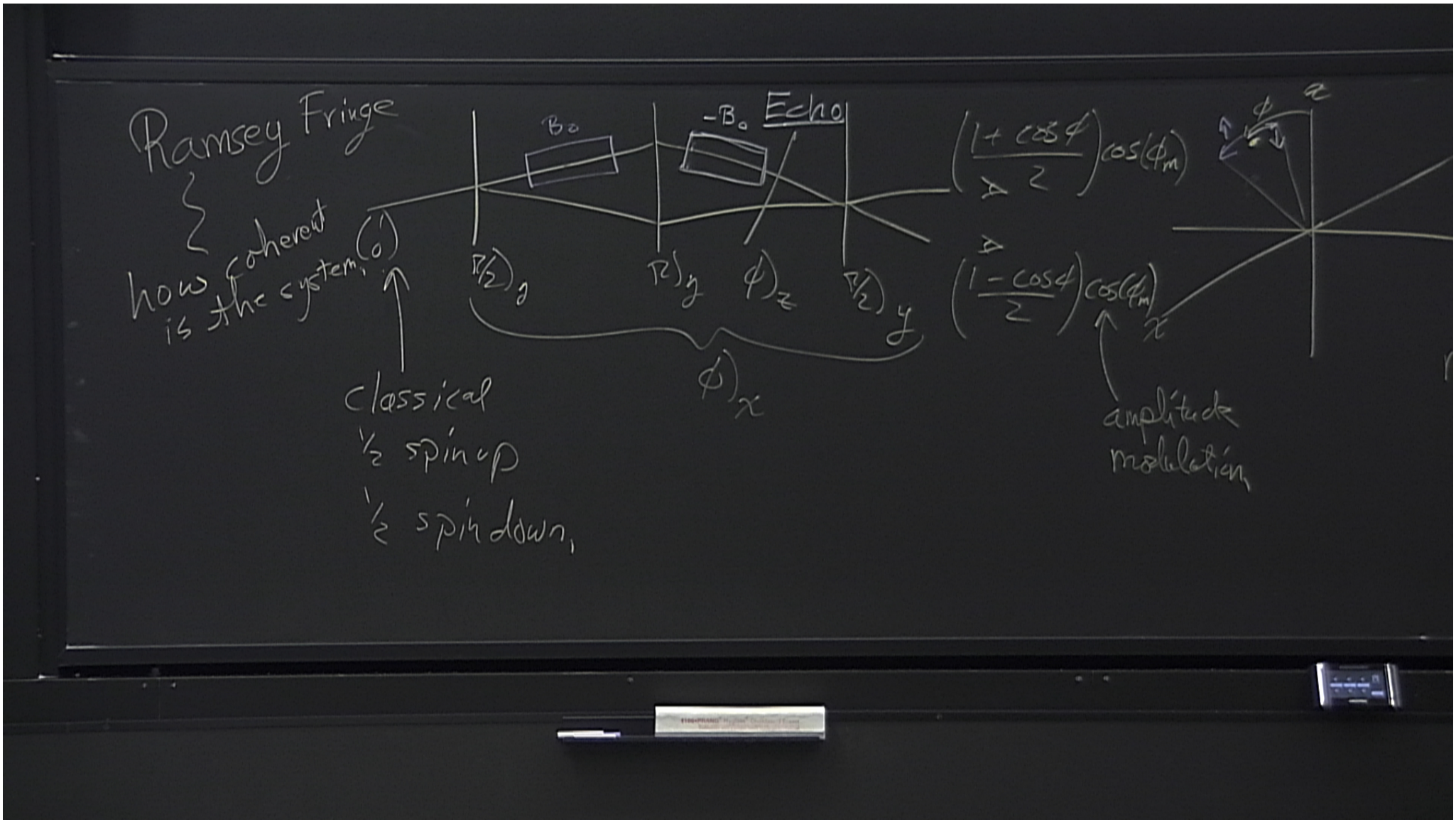
$$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$$

$$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$$



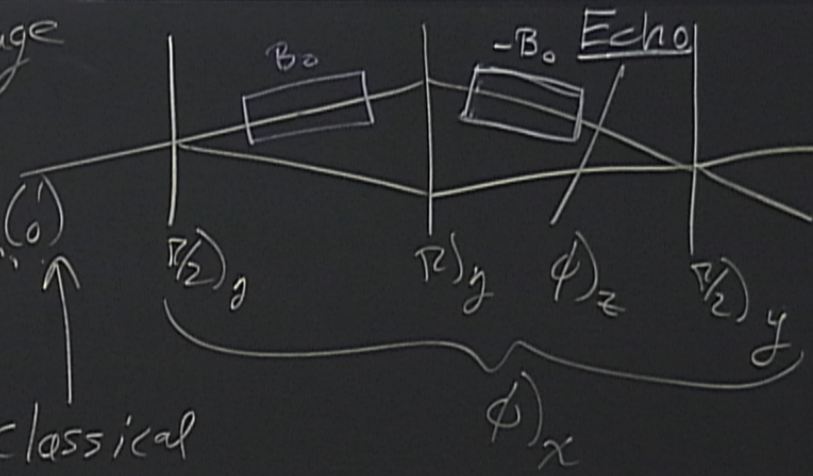
classical
½ spin up
½ spin down

amplitude modulation


Ramsey Fringe
how coherent is the system?
B_0
$-B_0$
Echo
$\pi/2)_y$
$\pi)_y$
$\phi)_z$
$\pi/2)_y$
$\phi)_x$
$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$
$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$
ϕ
z
x
classical
½ spin up
½ spin down
amplitude modulation

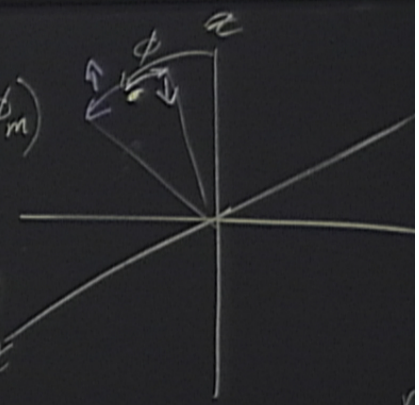
Ramsey Fringe

how coherent is the system?



$$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$$

$$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$$

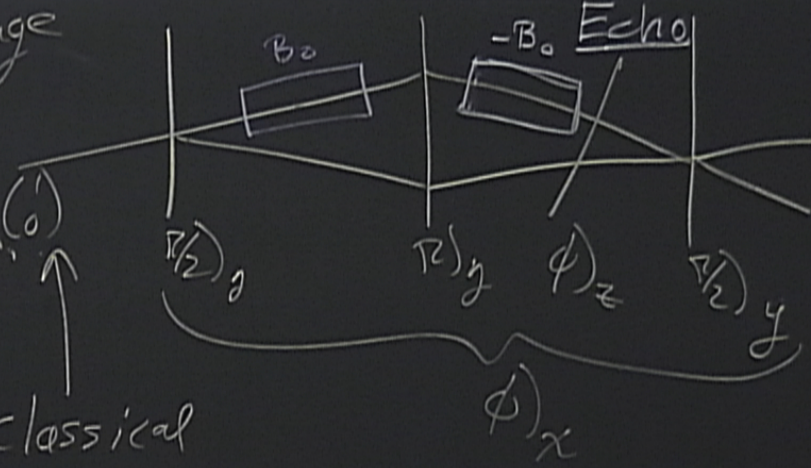


classical
½ spin up
½ spin down

amplitude modulation

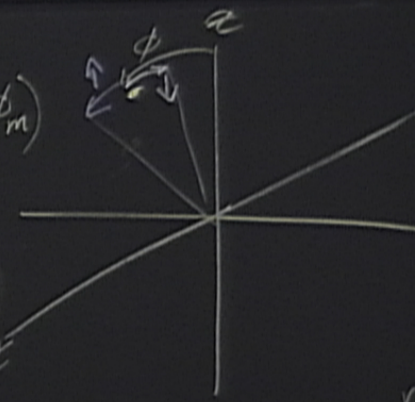
Ramsey Fringe

how coherent is the system?



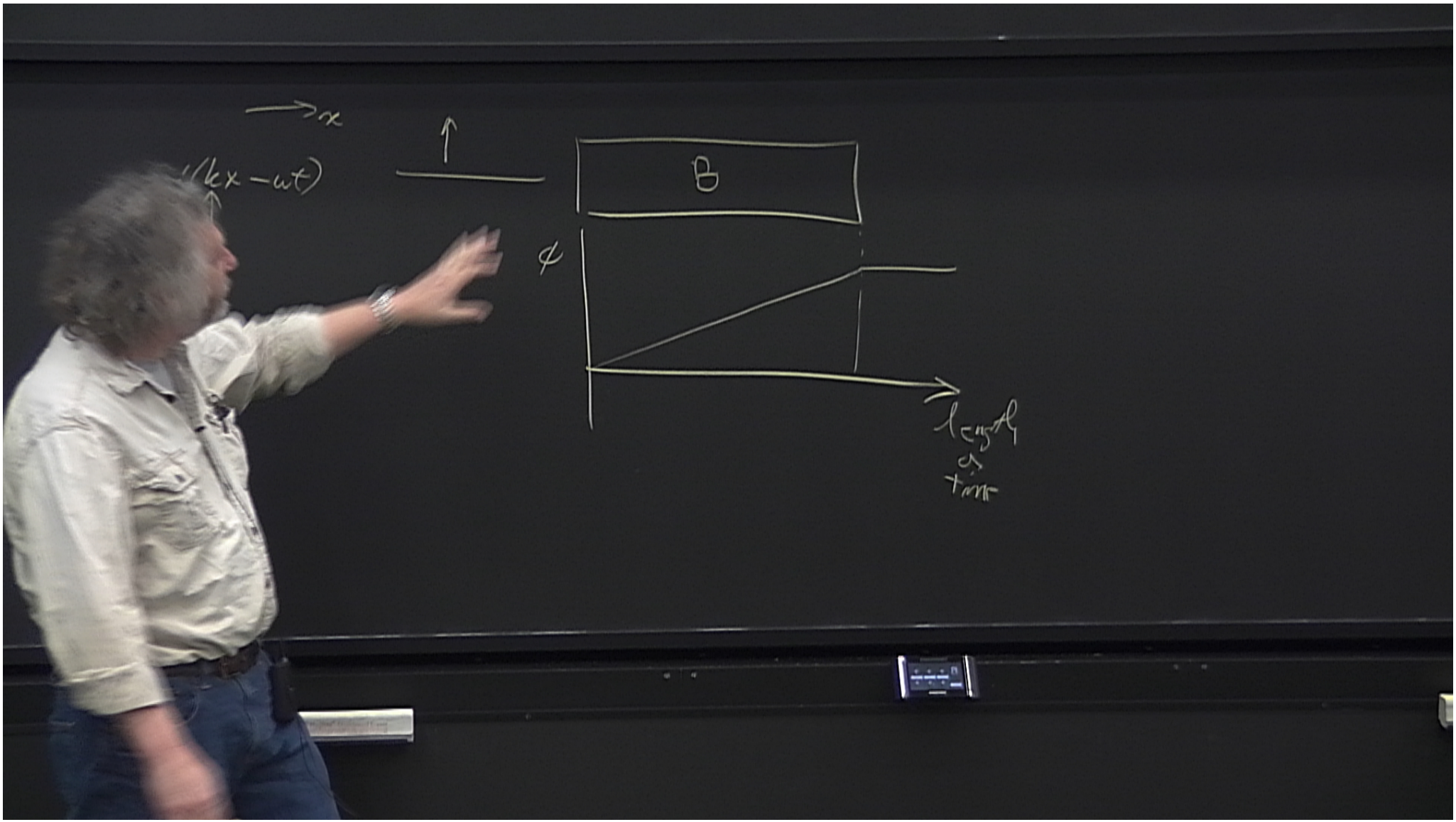
$$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$$

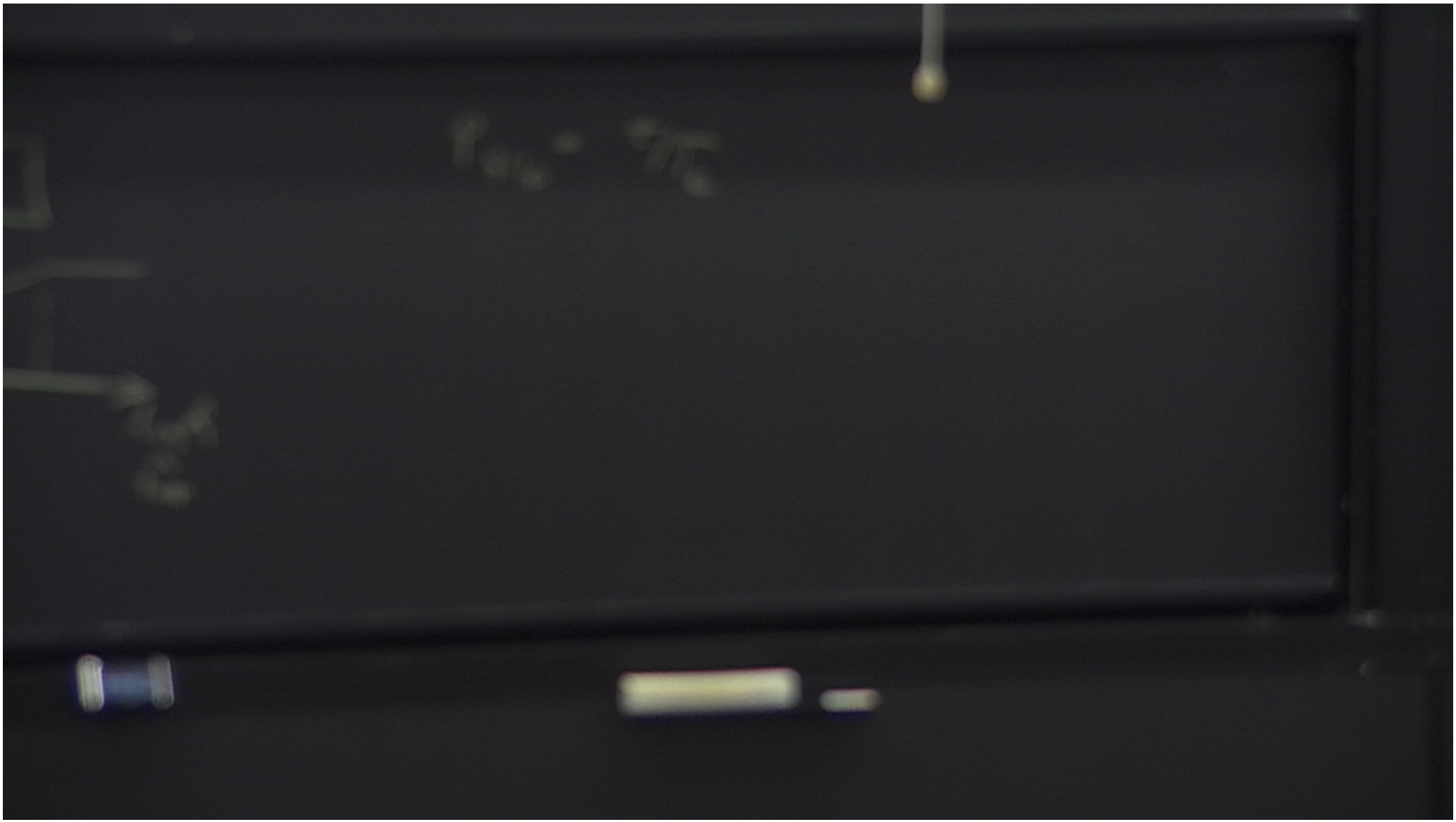
$$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$$

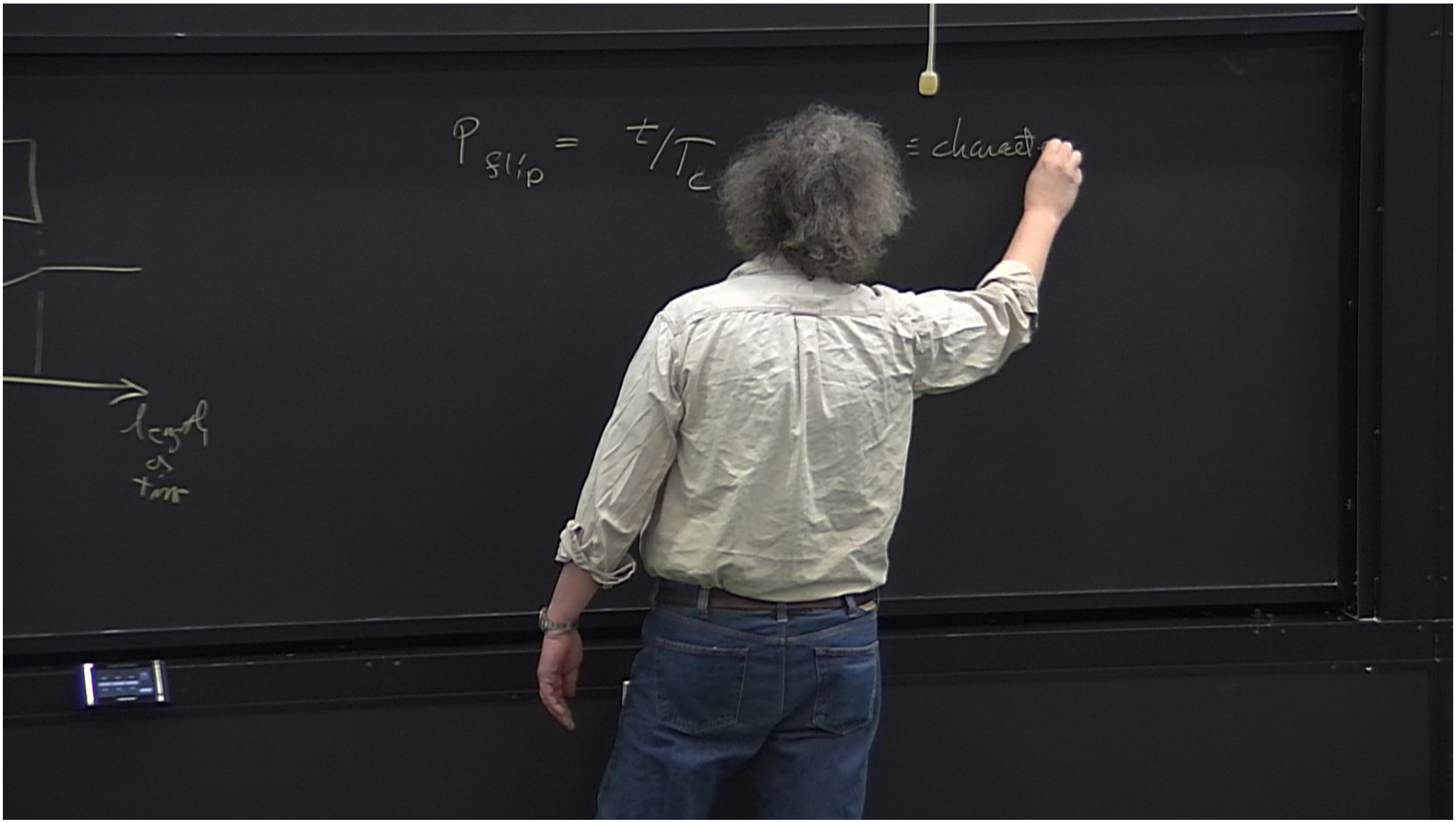


classical
½ spin up
½ spin down

amplitude modulation


x
(kx − ωt)
B
ϕ
length
or
time



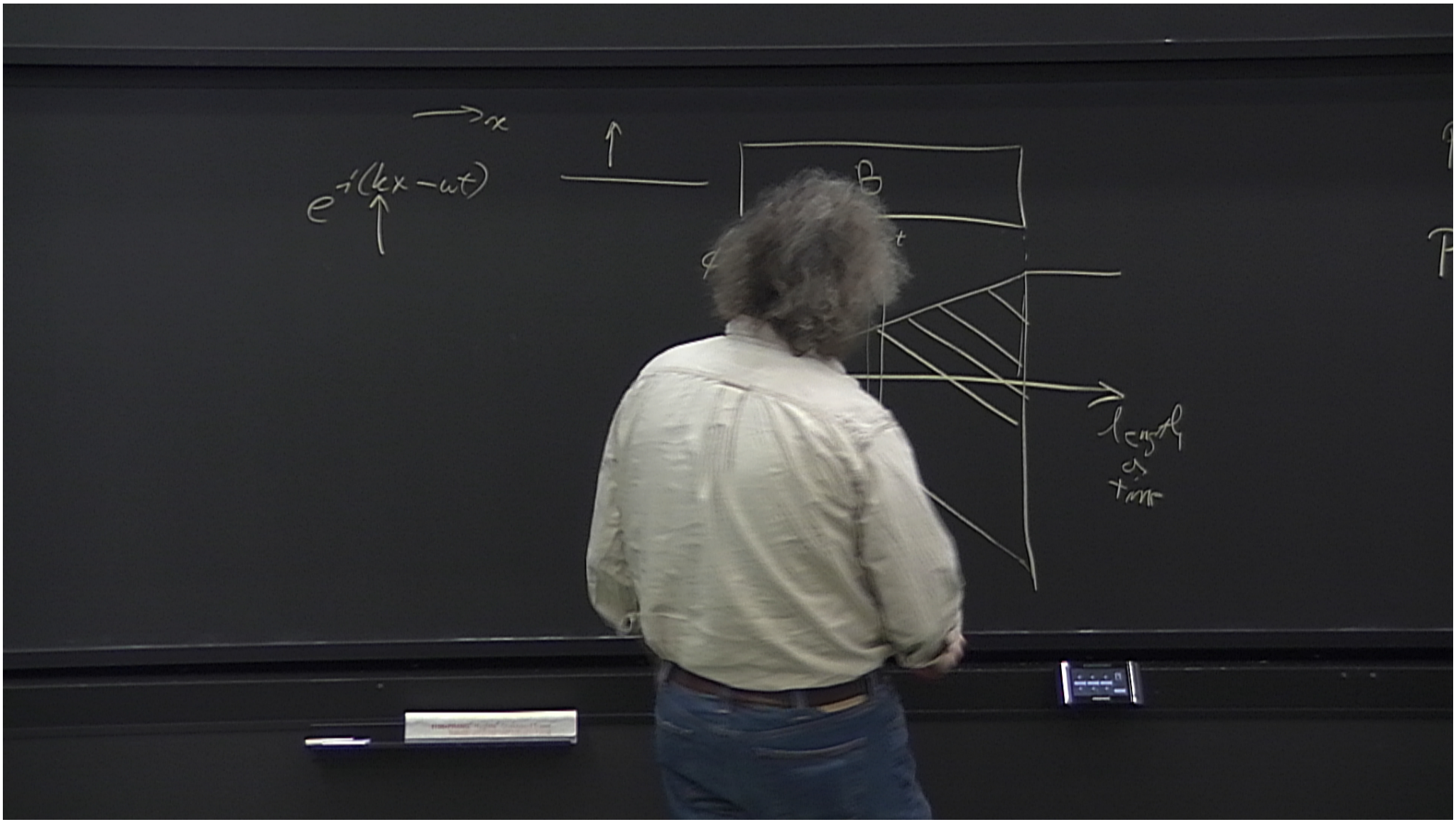

$P_{slip} = t/T_c$
length
or
time

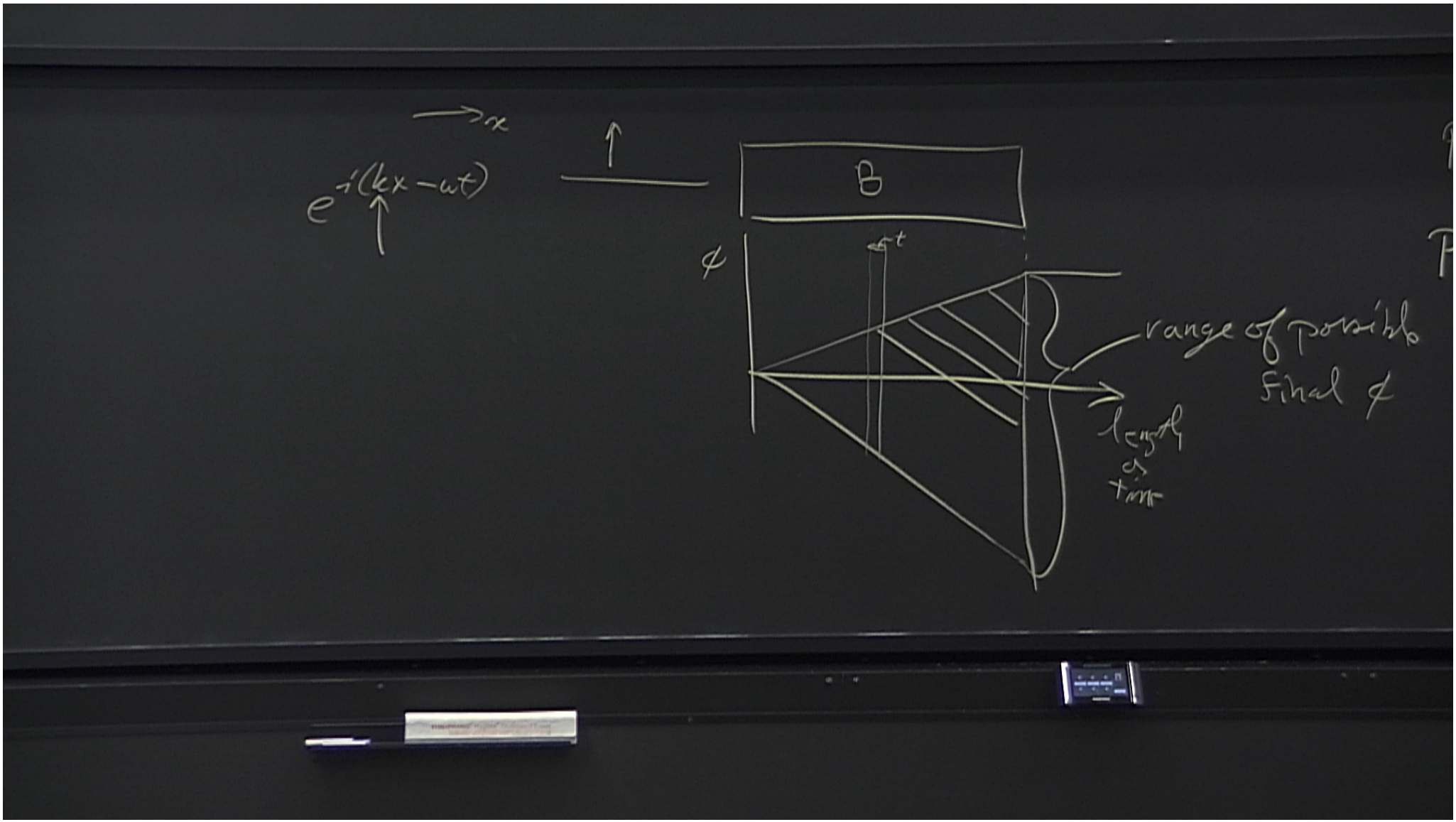
$$P_{flip} = t/T_c \quad ; \; T_c \equiv \text{characteristic time}$$

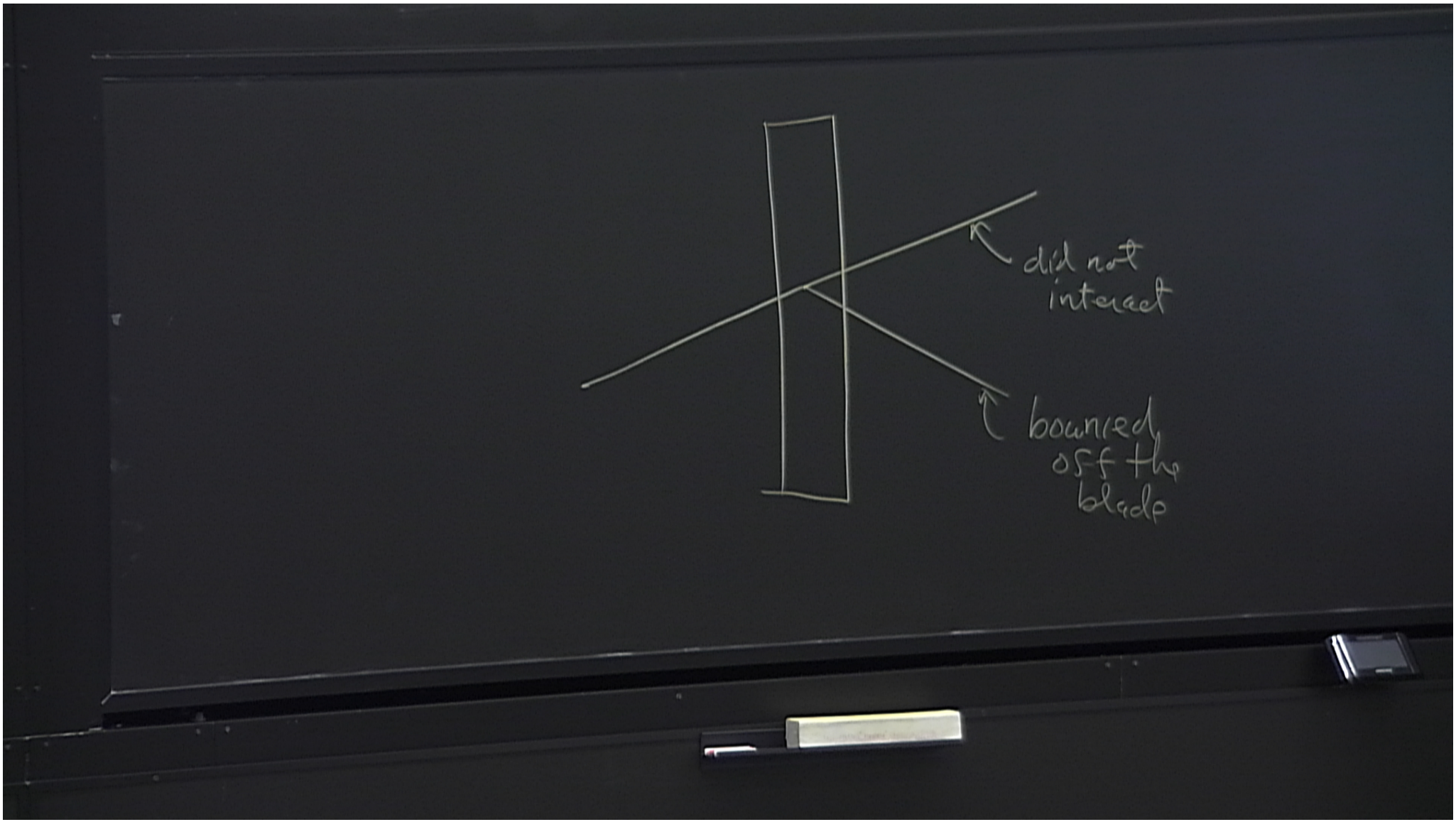
$$t \ll T_c$$

$$P_{no\,flip} = 1 - t/T_c$$

length
or
time

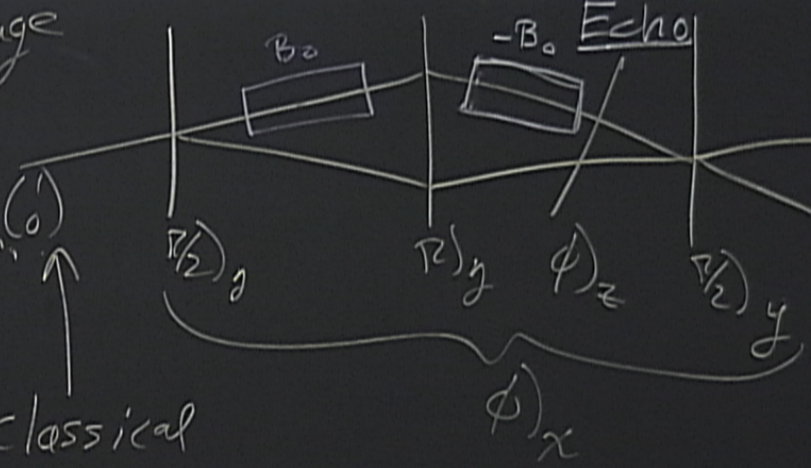

x
e^{-i(kx-ωt)}
B
t
length
or
time


$\rightarrow x$
$e^{-i(kx-\omega t)}$
B
ϕ
t
range of possible final ϕ
length of time


did not interact
bounced off the blade

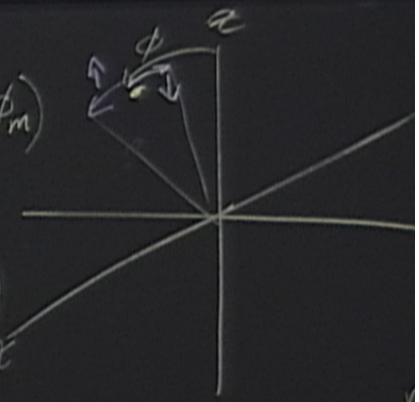
Ramsey Fringe

how coherent is the system?



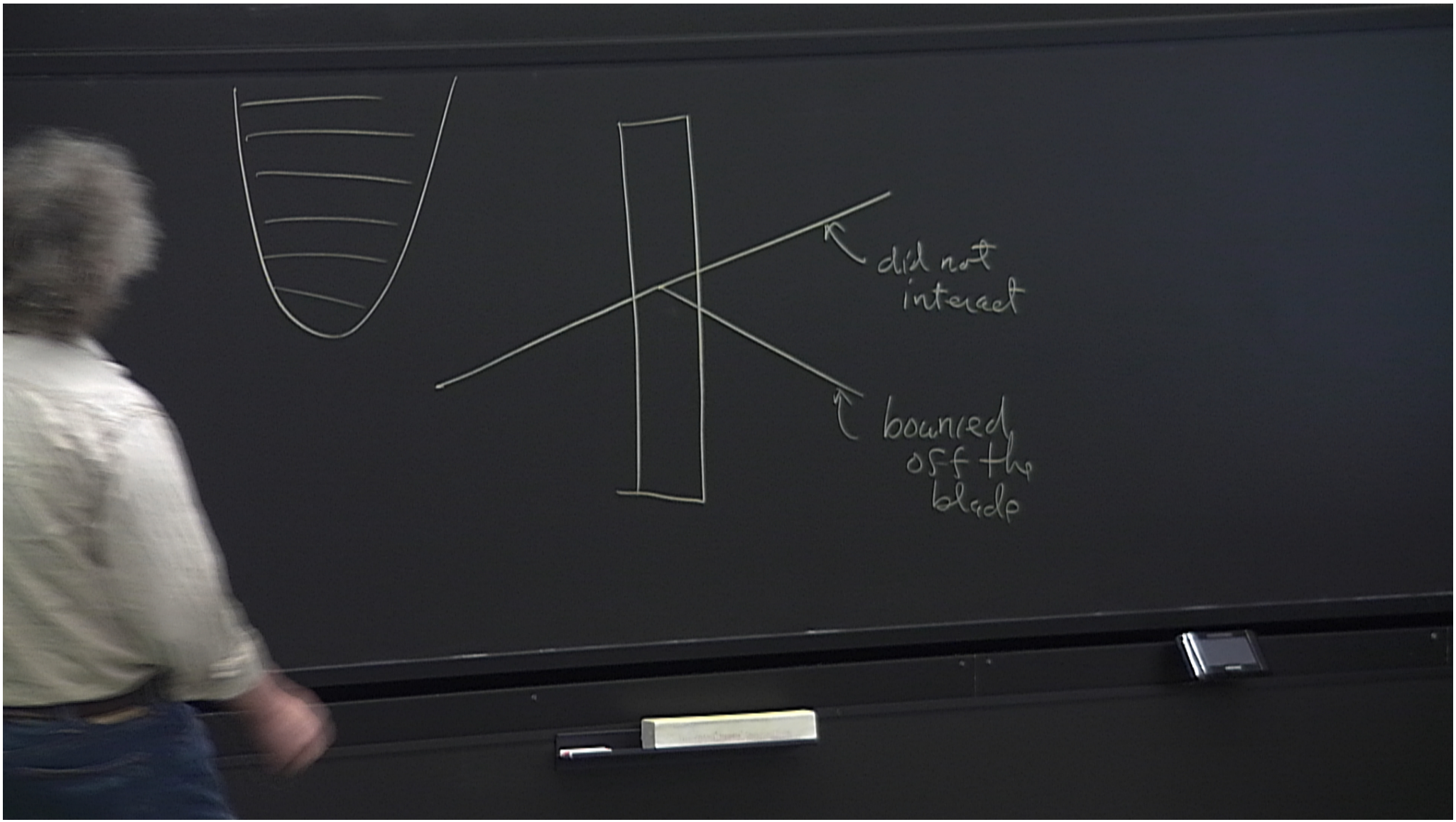
$$\left(\frac{1+\cos\phi}{2}\right)\cos(\phi_m)$$

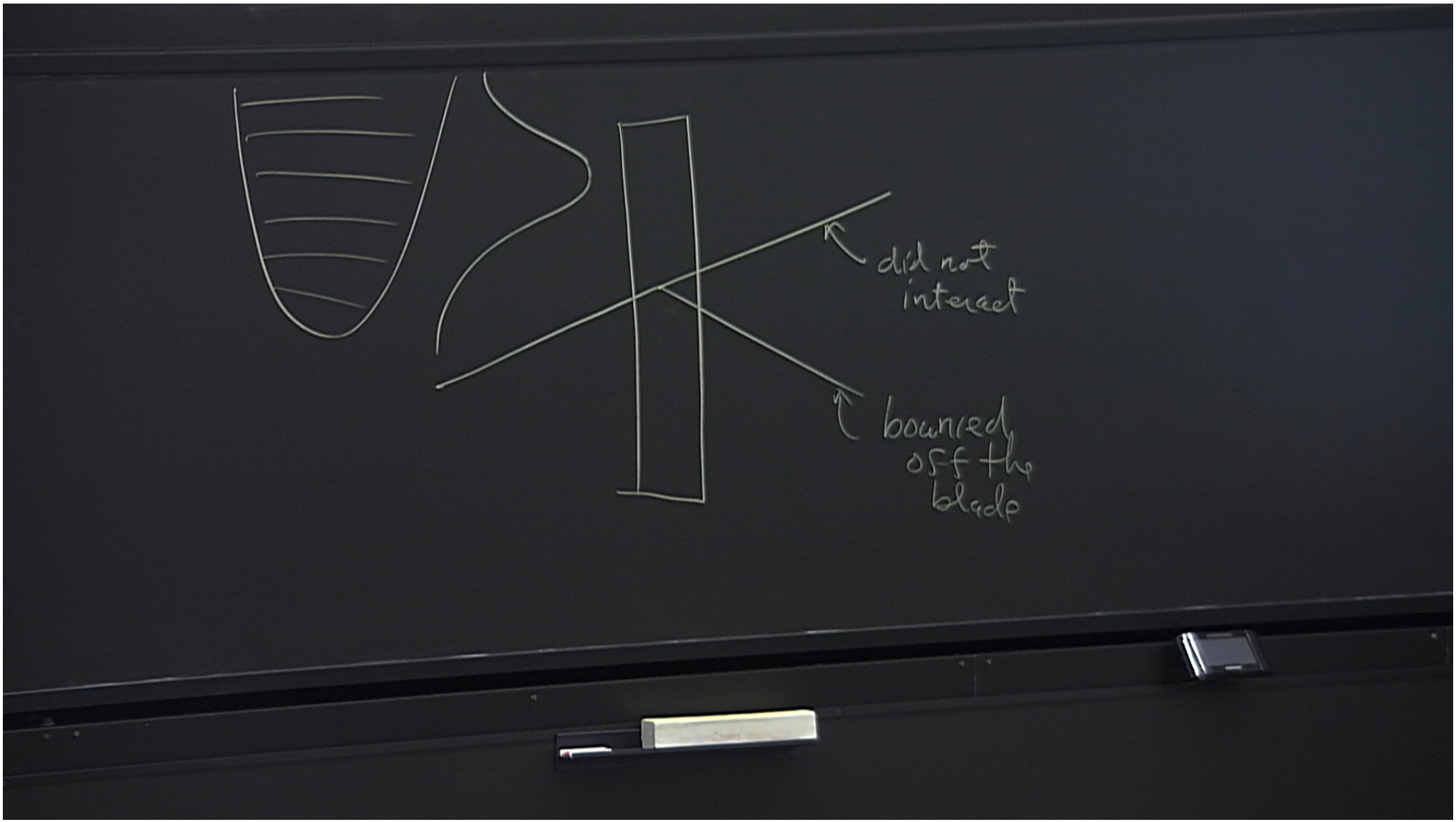
$$\left(\frac{1-\cos\phi}{2}\right)\cos(\phi_m)$$

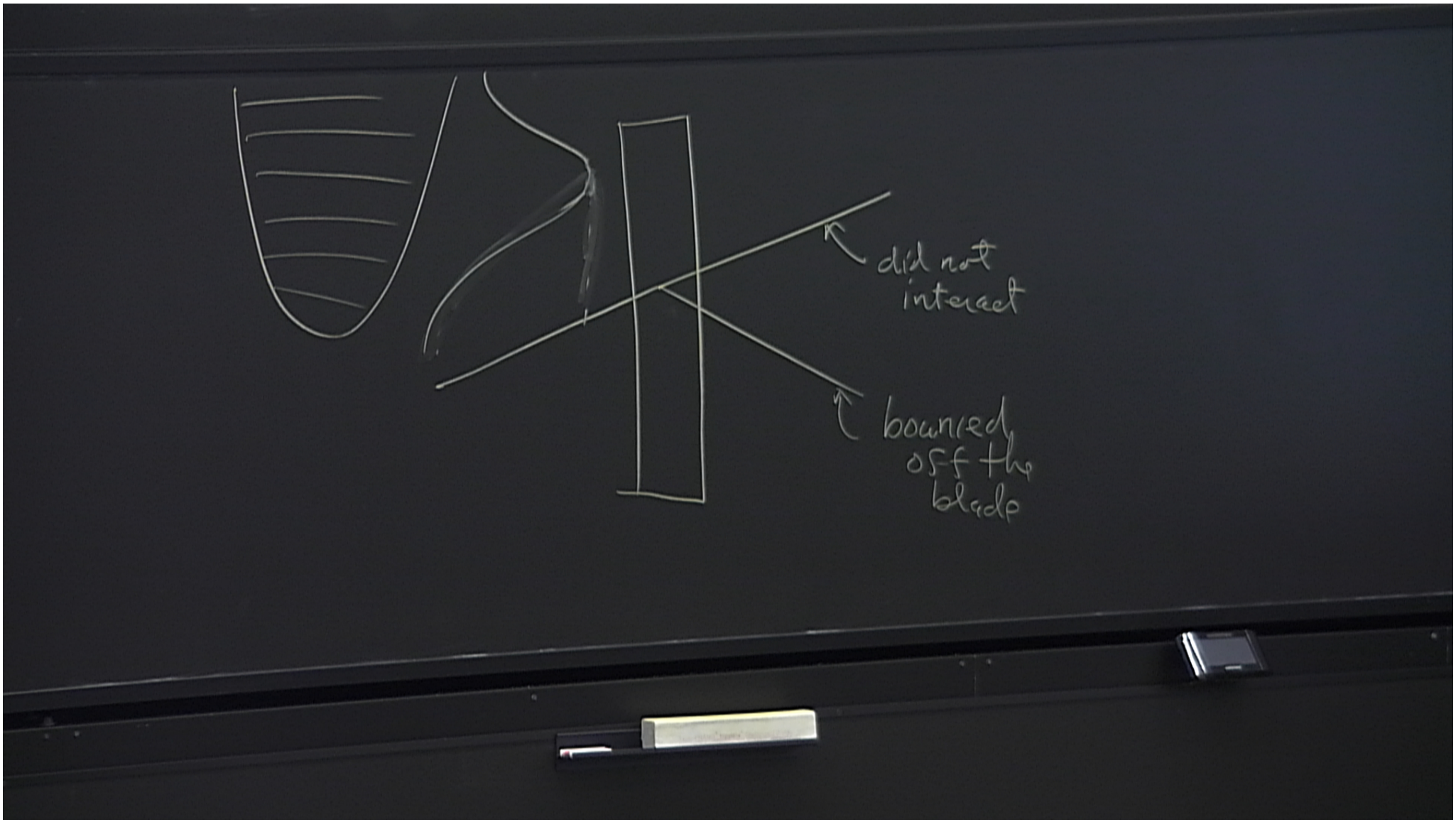


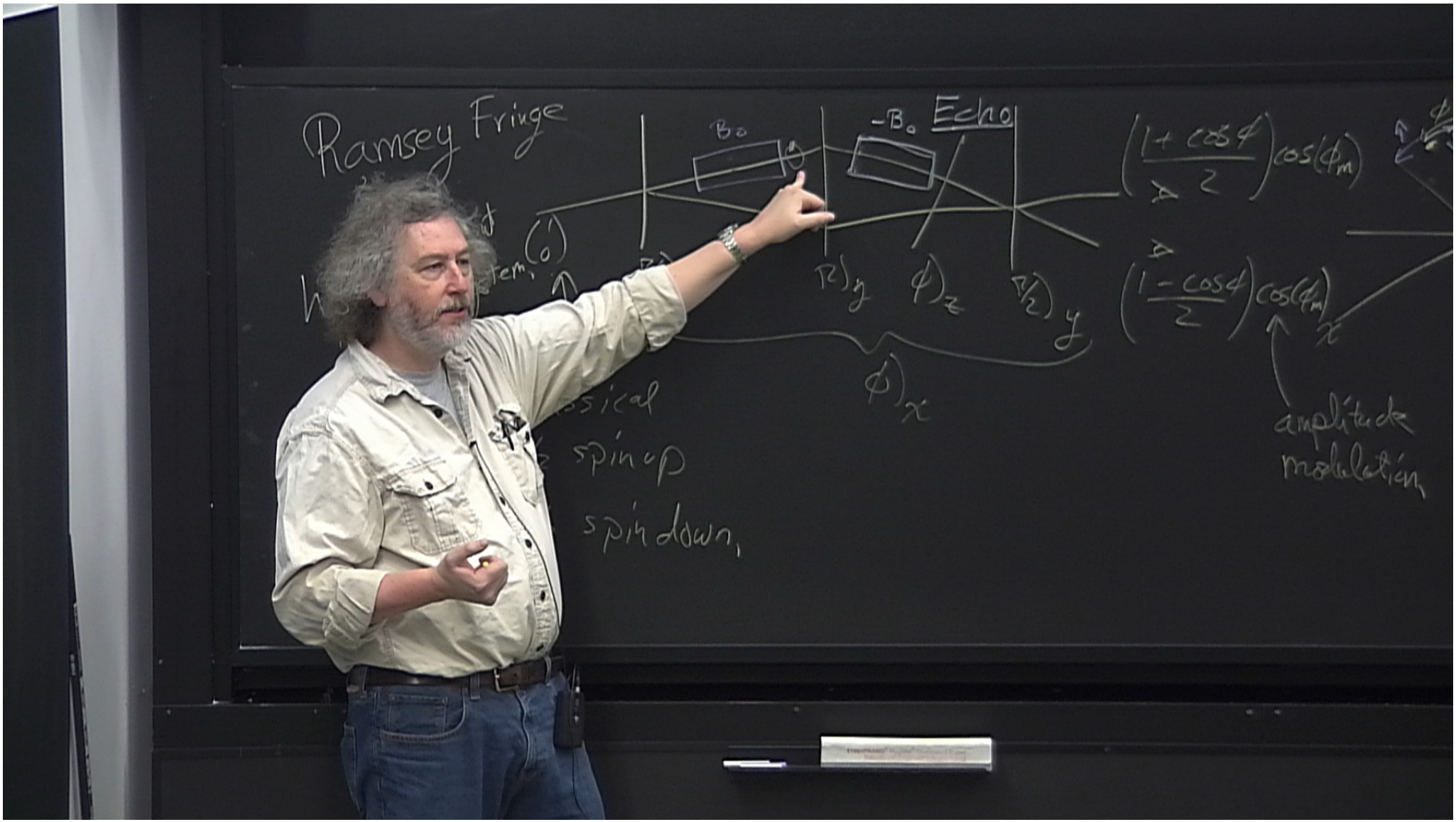
classical
½ spin up
½ spin down

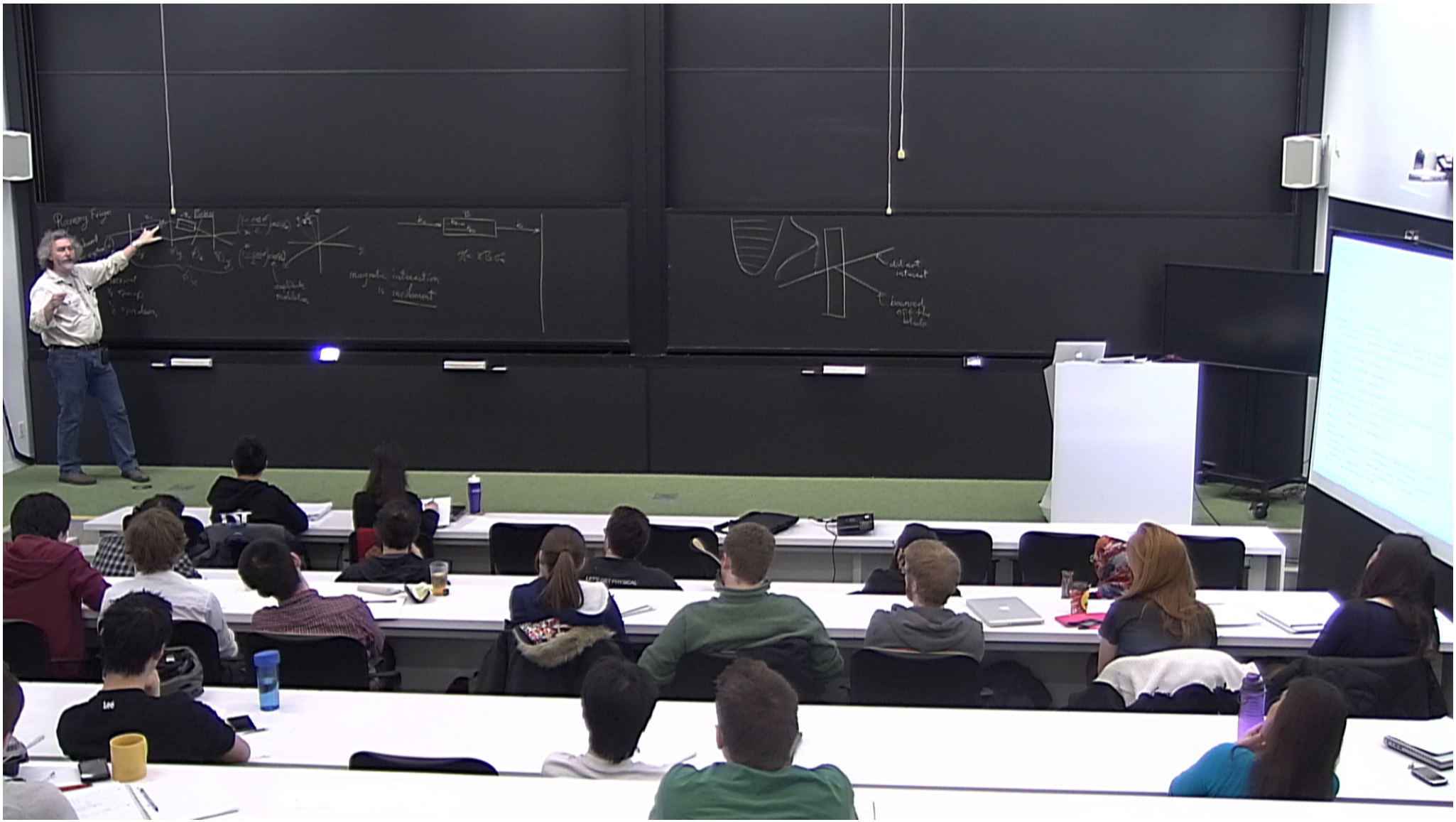
amplitude modulation

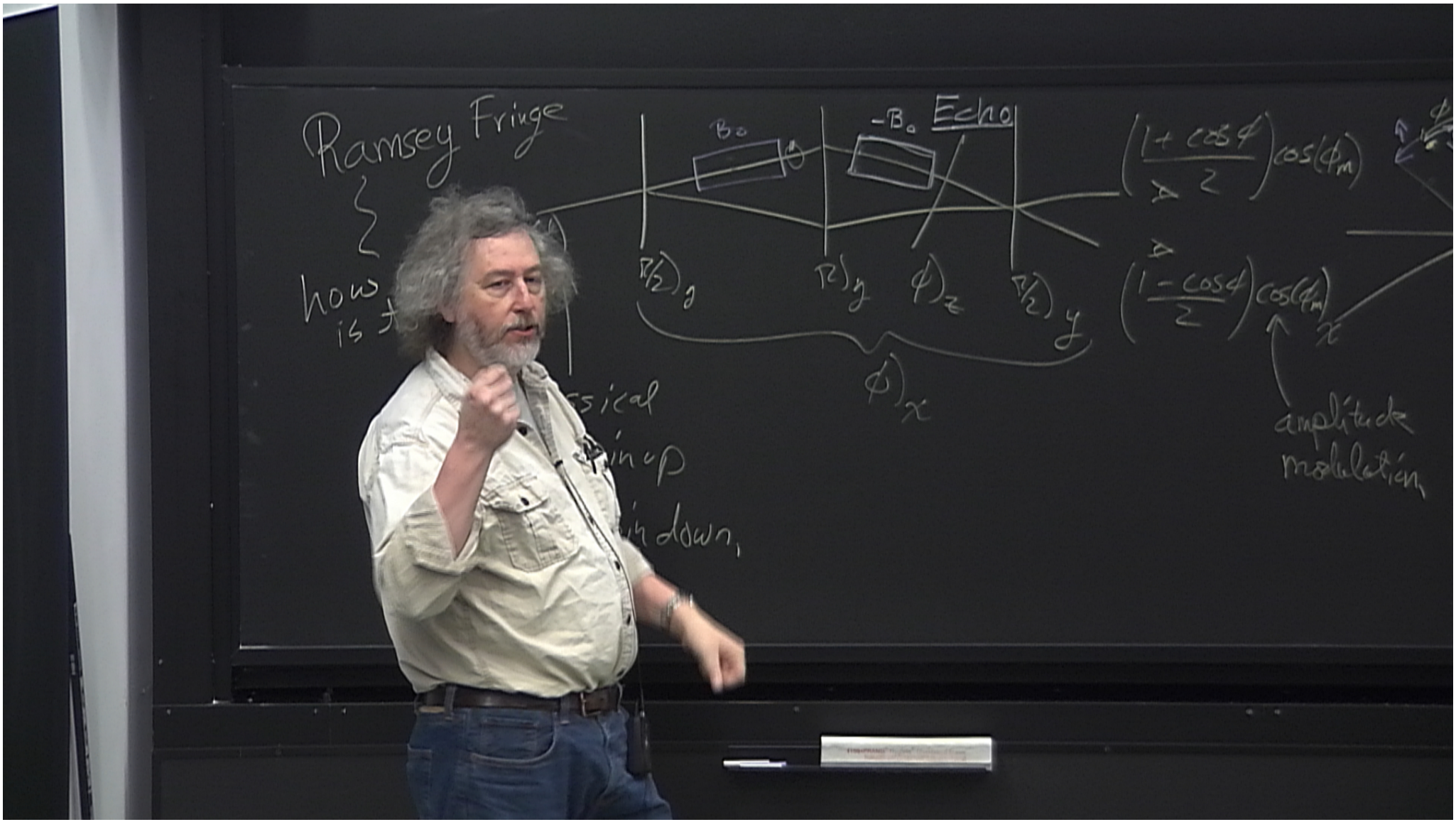

did not interact
bounced off the blade

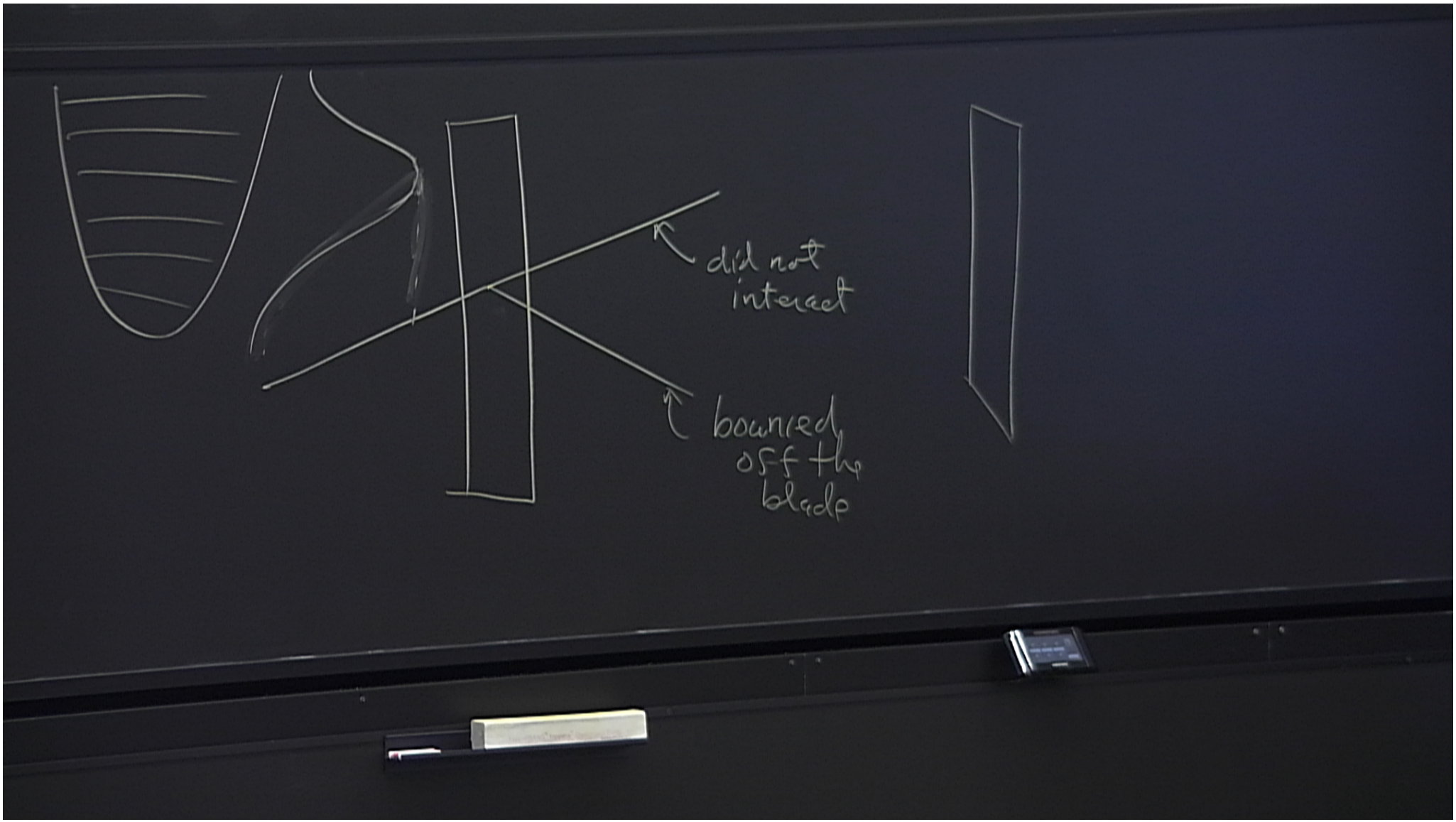

did not interact
bounced off the blade


did not interact
bounced off the blade


Ramsey Fringe
B₀
-B₀
Echo
spinup
spindown
amplitude modulation


magnetic interaction
is incoherent


Ramsey Fringe
how
is
B₀
-B₀
Echo
π/2)y
π)y
φ)z
π/2)y
φ)x
(1+cos φ / 2) cos(φm)
(1-cos φ / 2) cos(φm)
amplitude modulation


did not interact
bounced off the blade

Wolfram CDF Player

- a process that flips the spin

These are described by the following two operators. I have made the probabilities dependent on time so that the spin flip looks like a relaxation process. Of course they add up to 1.

Notice that even though the spin state is the identity in our example, the identity is composed of spins being up or down, so a spin flip maintains its meaning.

phase evolution with spin flips

We showed that the evolution of the phase was a rotation about the z axis. So let's look only at this part.

```
U = MatrixExp[I 0.2 PauliMatrix[3]];
Ui = MatrixExp[-I 0.2 PauliMatrix[3]];
ρu[0] = {{0, 1}, {1, 0}};
ρu[n_] := ρu[n] = .95 U . ρu[n - 1] . Ui + .05 Ui . ρu[n - 1] . U;
ρu[100];
ρd[0] = {{0, 1}, {1, 0}};
ρd[n_] := ρd[n] = .95 Ui . ρd[n - 1] . U + .05 U . ρd[n - 1] . Ui;
ρd[100];
Show[{ListPlot[Table[ Re[Tr[PauliMatrix[1] . ρu[n]] / 2], {n, 1, 100, 1}],
        {PlotRange → {{1, 1}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.003]},
         DisplayFunction → Identity}],
  ListPlot[Table[Re[Tr[PauliMatrix[2] . ρu[n]] / 2], {n, 1, 100, 1}],
        {PlotStyle → {RGBColor[1, 0, 0], Thickness[0.003]},
         DisplayFunction → Identity}]}, DisplayFunction → $DisplayFunction]
```

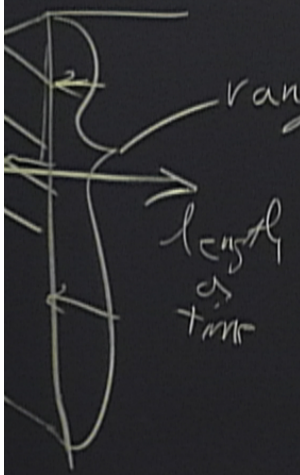
1.0

200%

$U_m(\alpha)$; $P_{flip} = t/T_c$; T_c = characteristic time

$t \ll T_c$

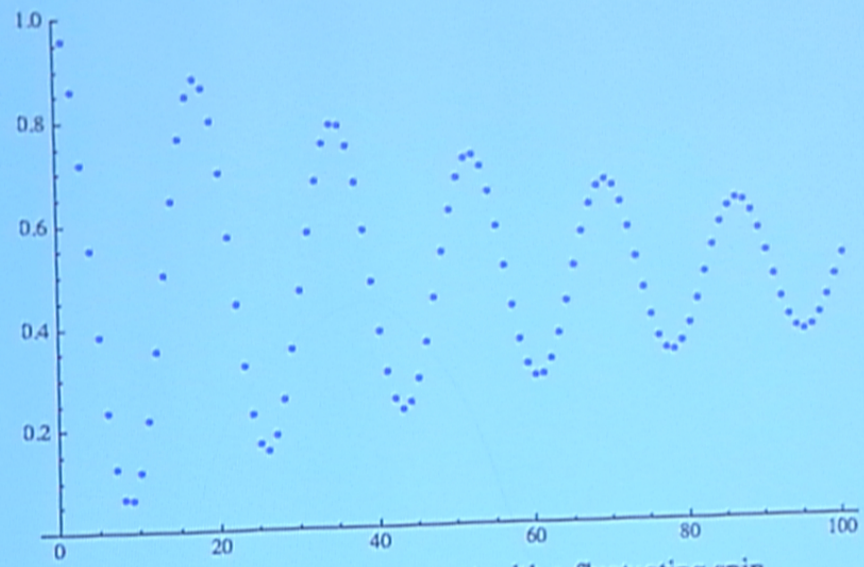
$U_m(\alpha)$; $P_{no\ flip} = 1 - t/T_c$



<u>decoherence</u>

Wolfram CDF Player

```
ListPlot[
 Table[ (1 + Re[Tr[PauliMatrix[1] . ρu[n]] / 4] + Re[Tr[PauliMatrix[1] . ρd[n]] / 4]) / 2,
  {n, 1, 100, 1}],
    {PlotRange → {0, 1}, PlotStyle → {RGBColor[0, 0, 1], Thickness[0.003]}}]
```



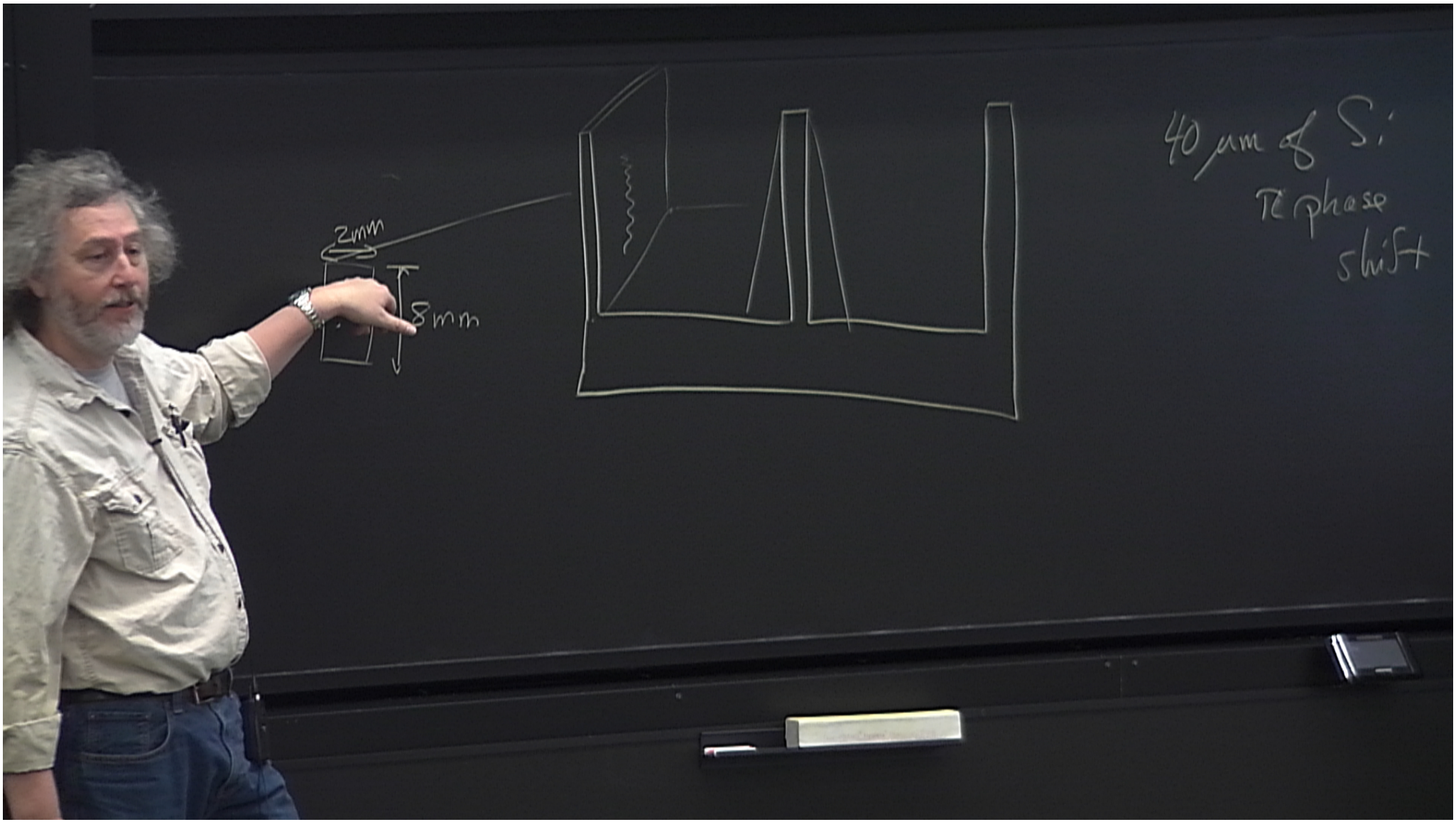
This is the contrast curve we expect with a fluctuating spin.

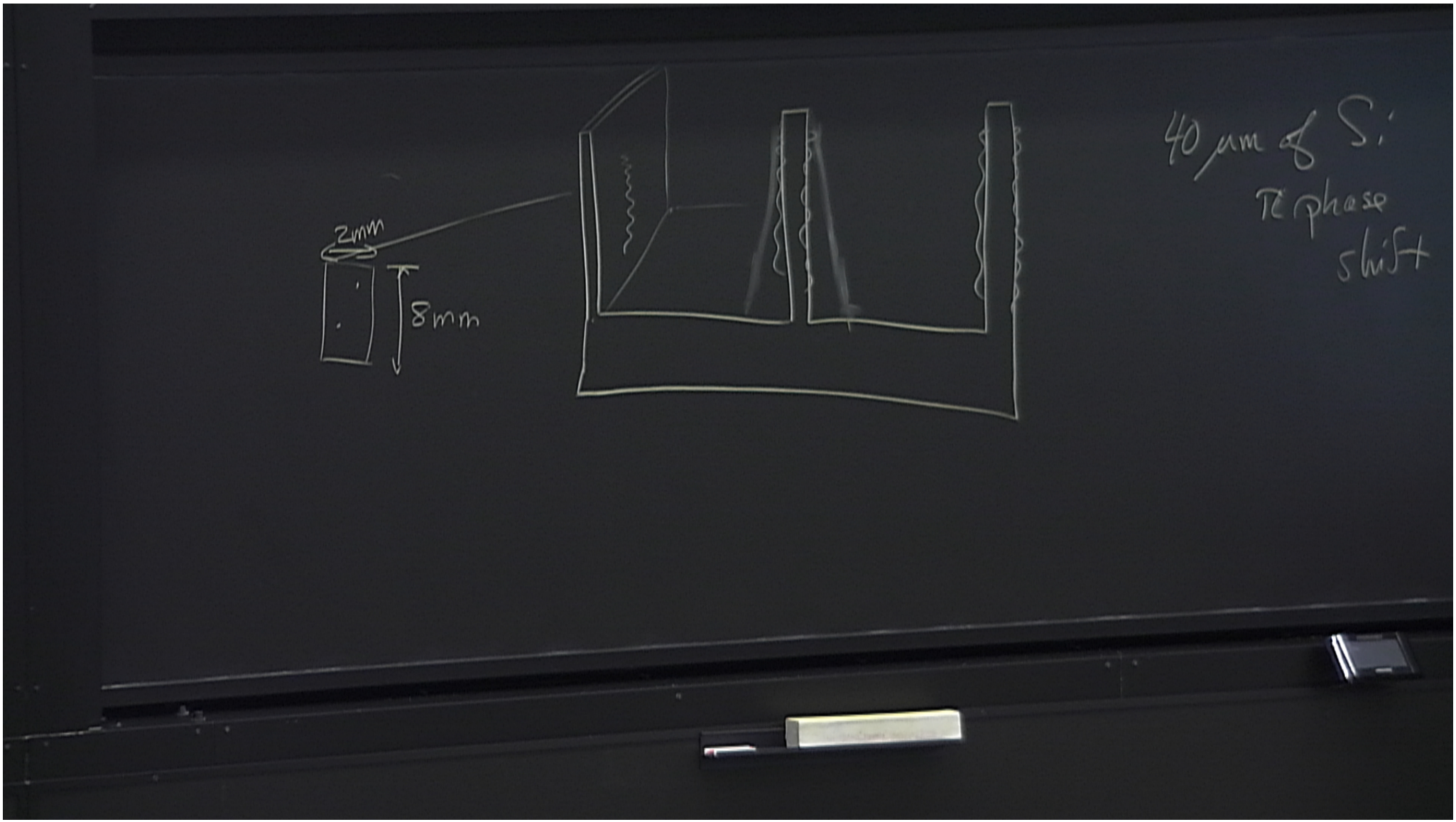
- Problem: Show that as the time to flip the spin reduces that the contrast returns. This is an example of so-called self decoupling.

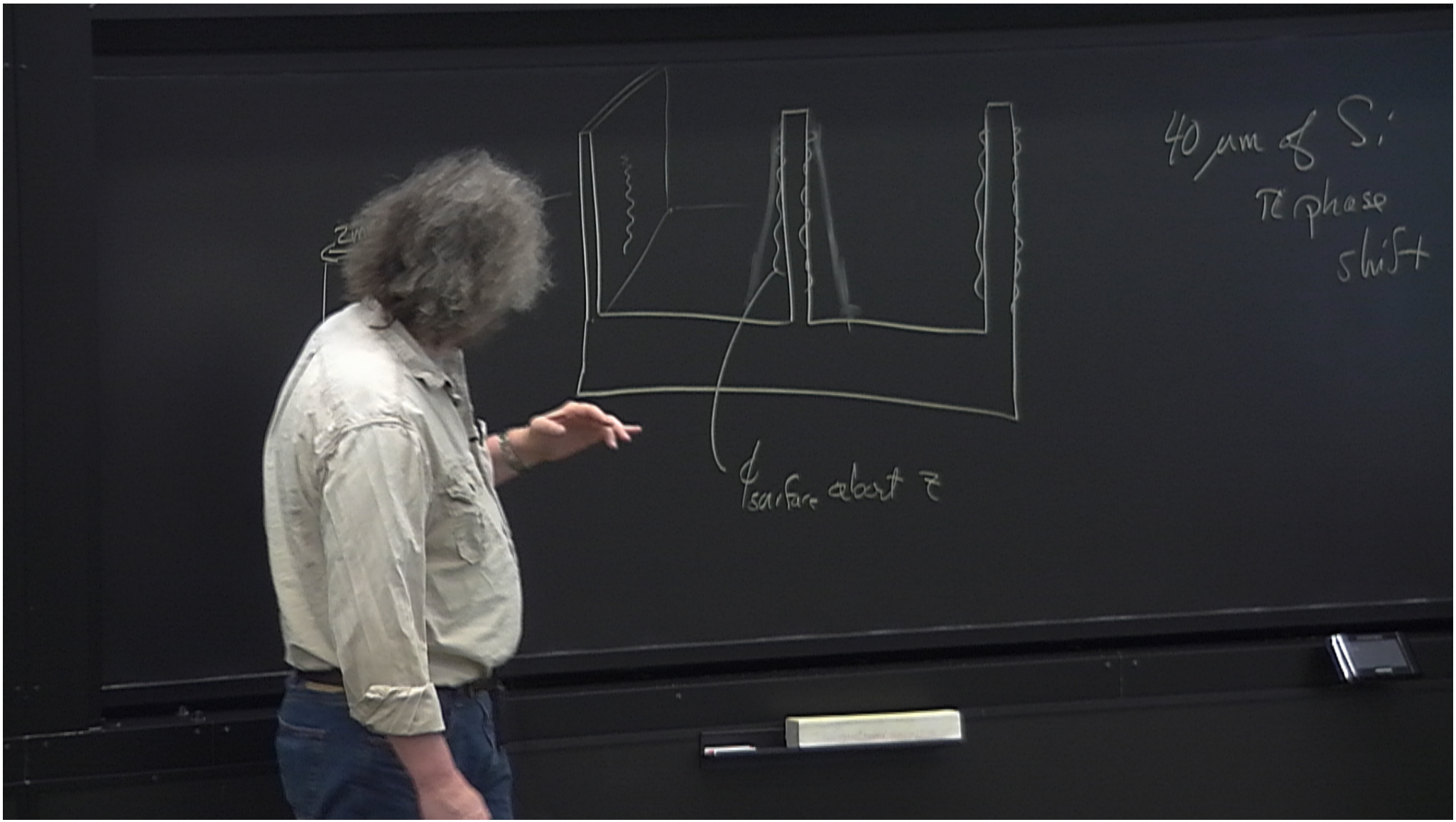
Superoperator

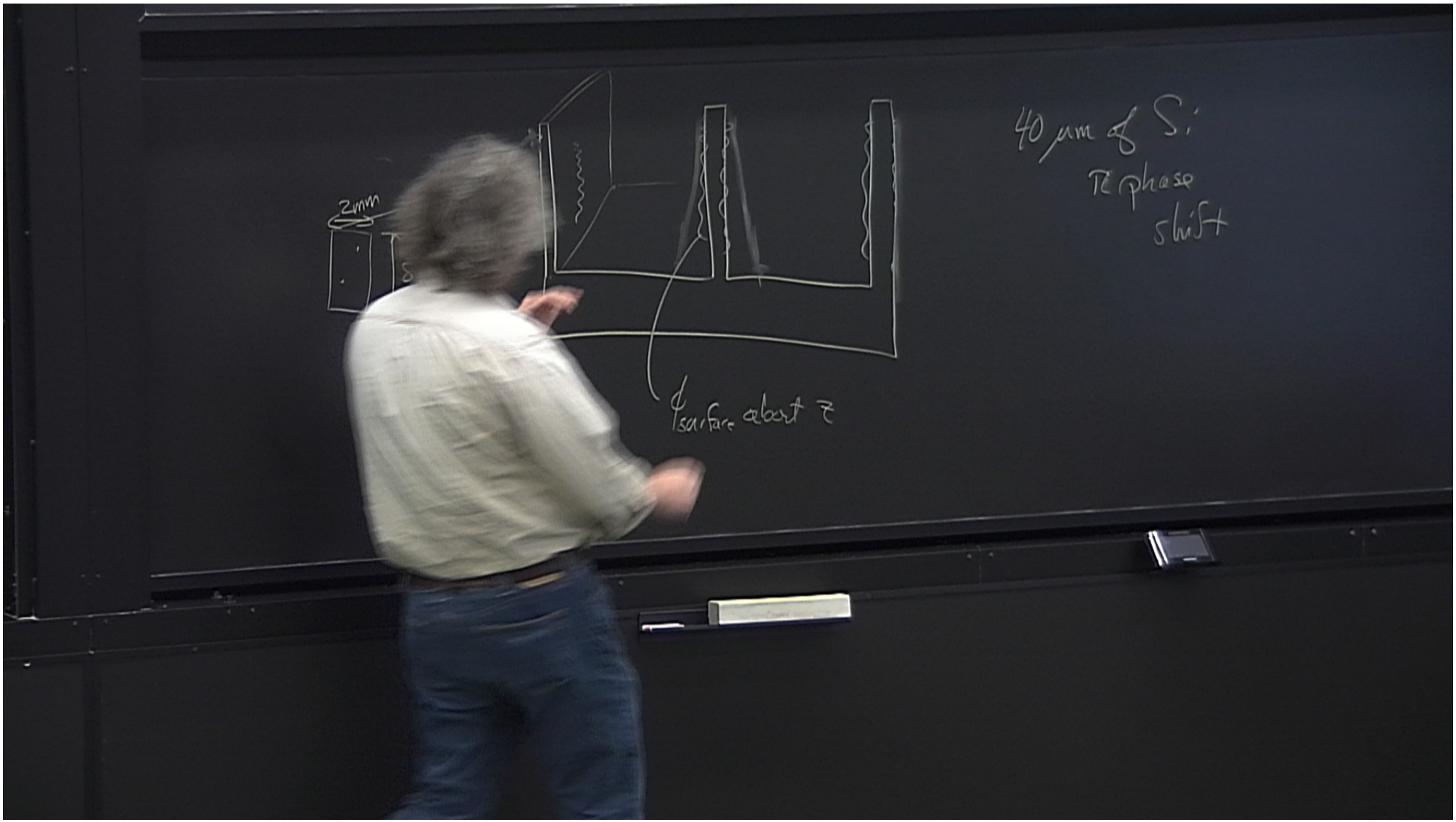
The map for the fifth experiment is not unitary and it is convenient to use new tools to describe the dynamics. Note that above we described this by considering a convex sum of unitary processes. Here we define the superoperator as a complete description of the dynamics for a specified instant.

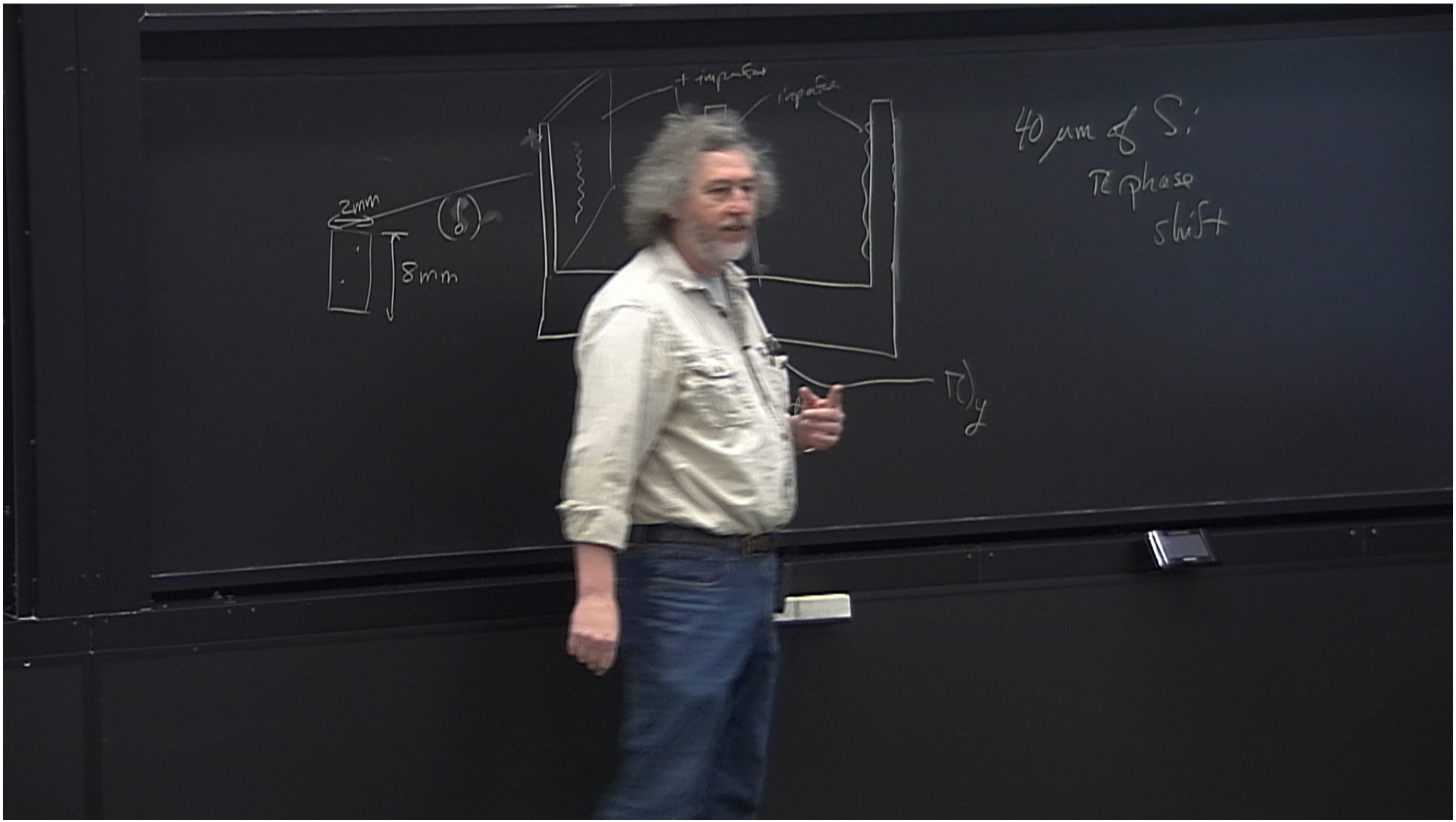
200%

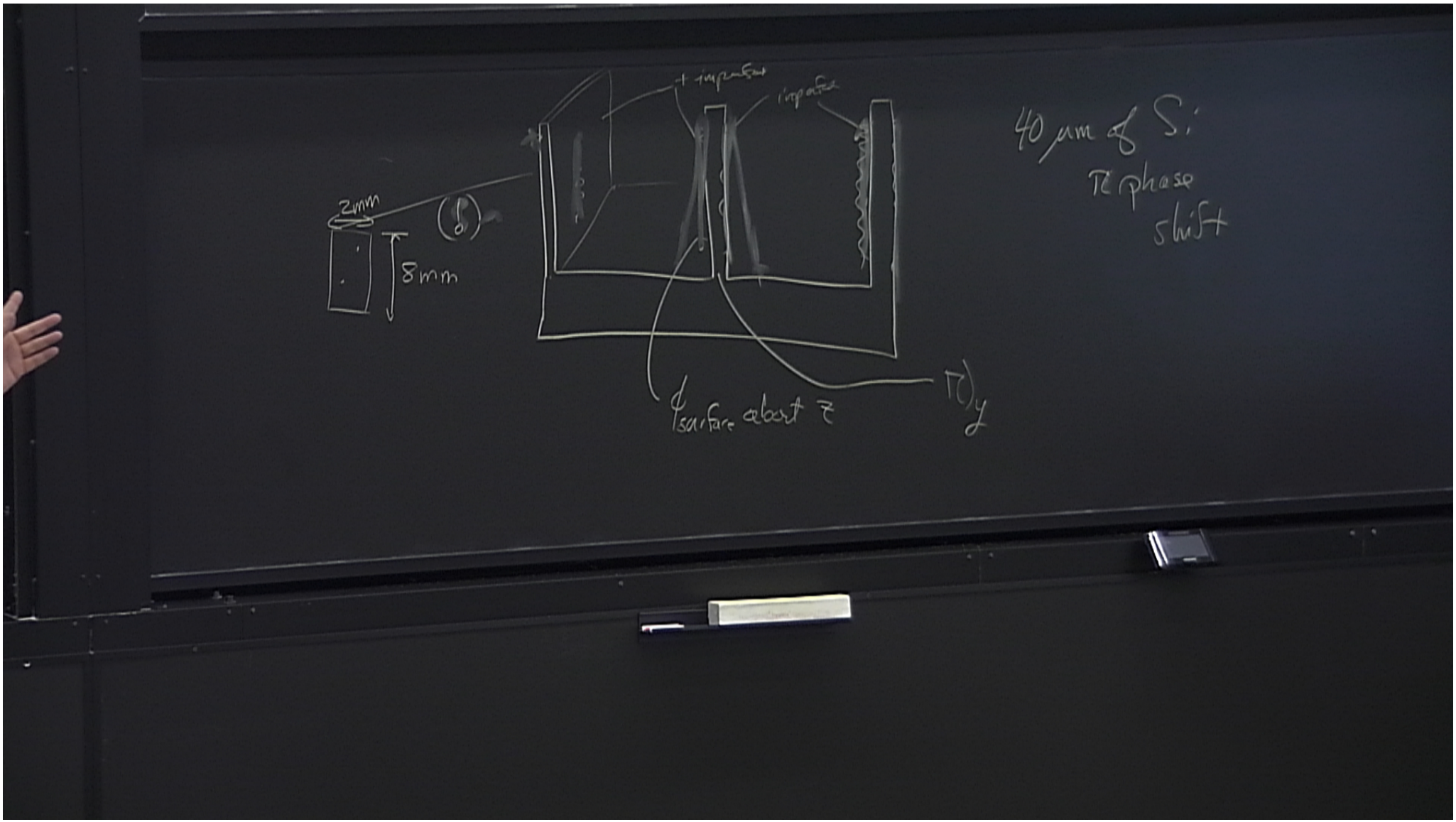

2mm
8mm
40 μm of Si:
π phase
shift


2mm
8mm
40 μm of Si:
π phase
shift


40 μm of Si:
π phase
shift
φsurface about z


2mm
40 μm of Si
π phase
shift
φsurface about π


2mm
8mm
40 μm of Si:
π phase
shift


2mm
8mm
40 μm of Si:
π phase
shift