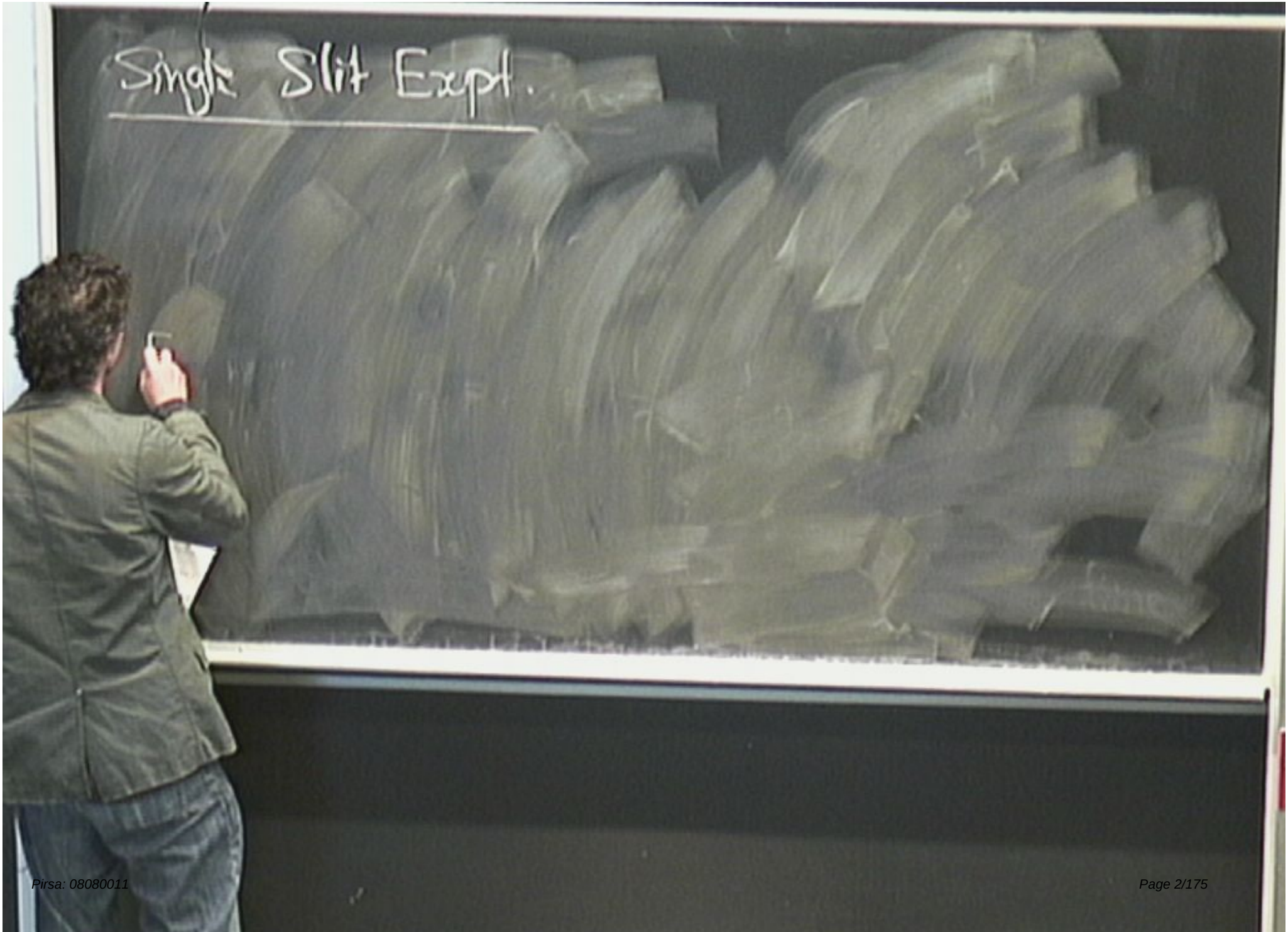
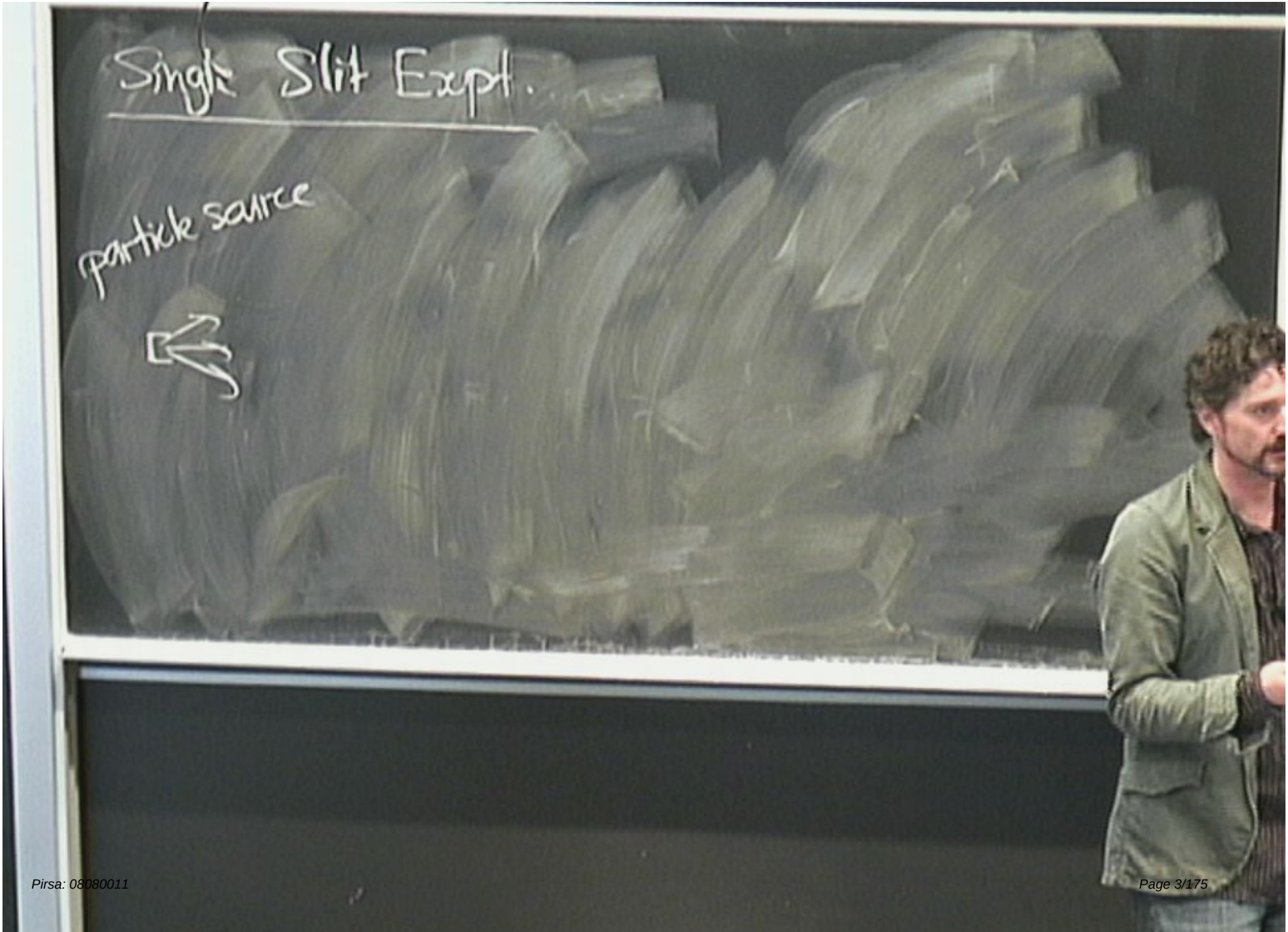
Title: Quantum 1

Date: Aug 10, 2008 10:30 AM

URL: http://pirsa.org/08080011

Abstract:


Single Slit Expt.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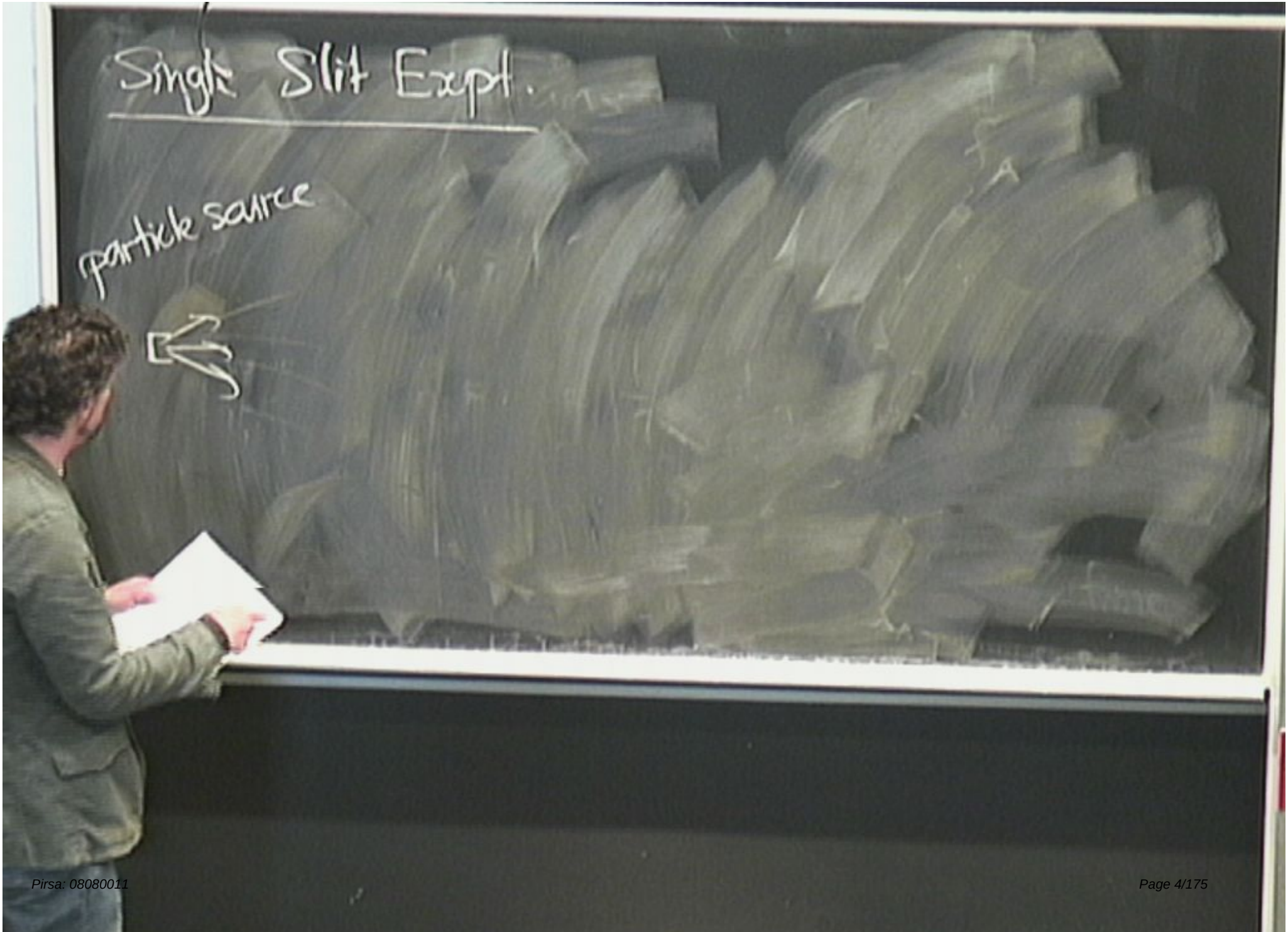
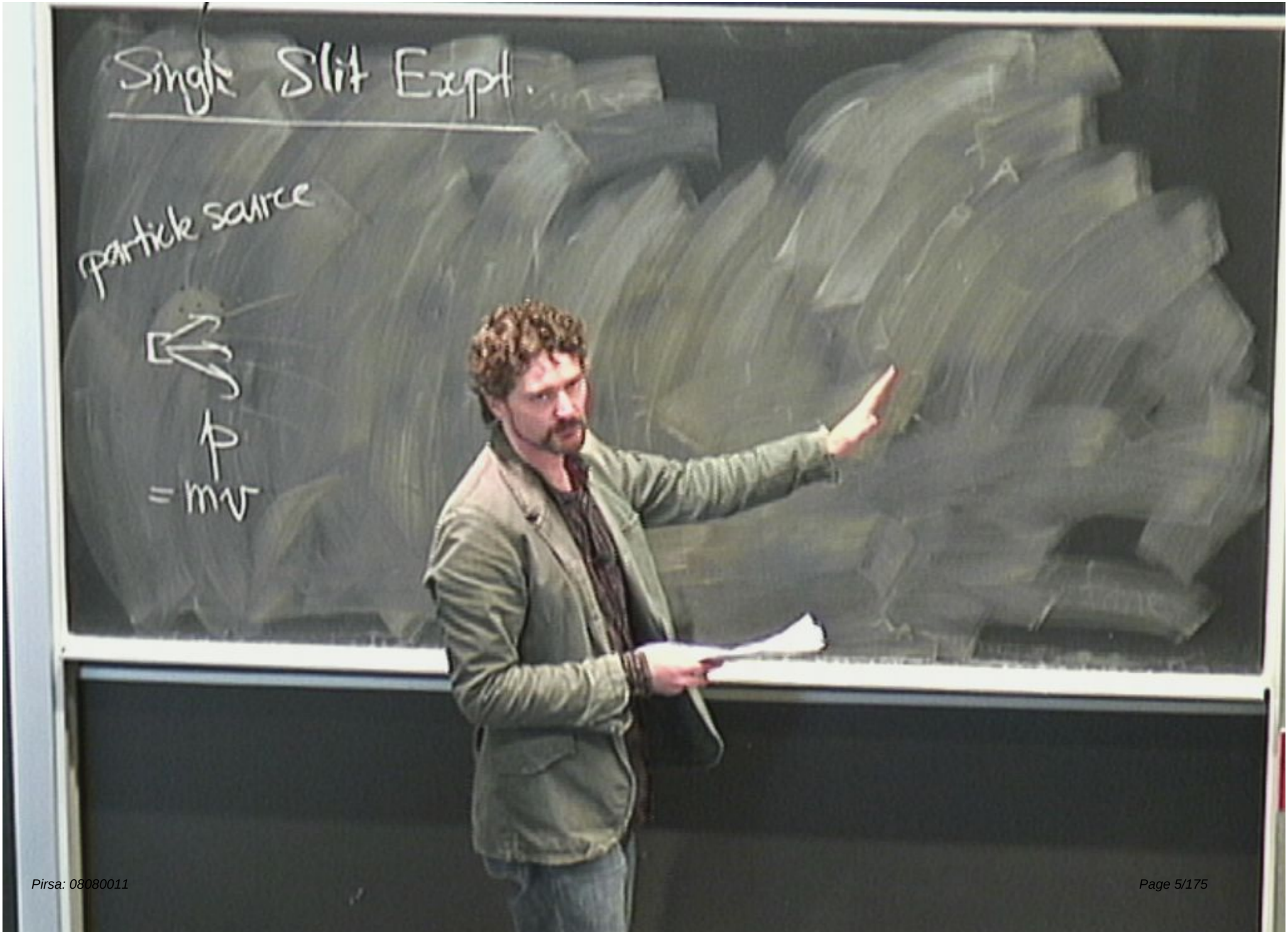
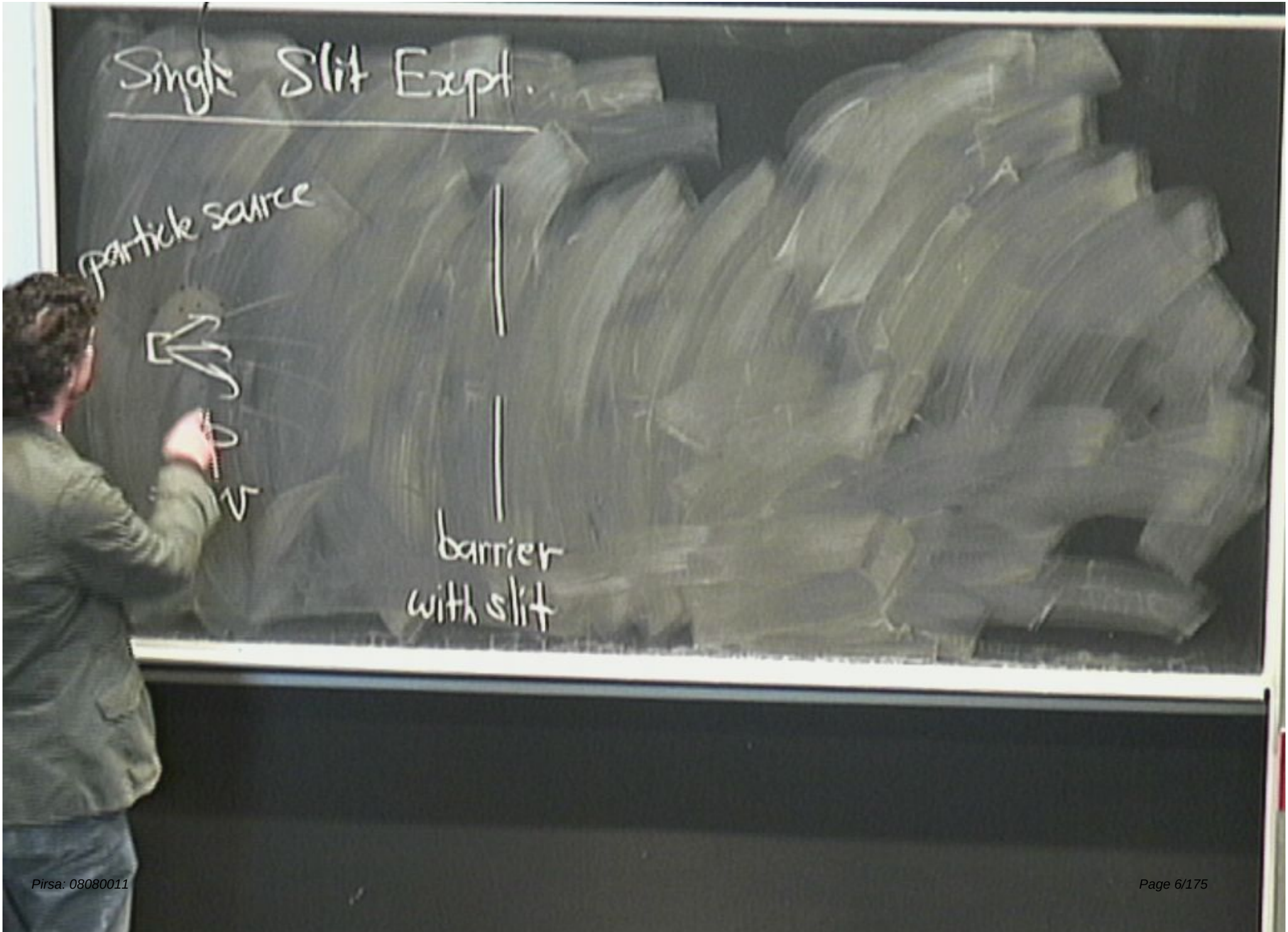
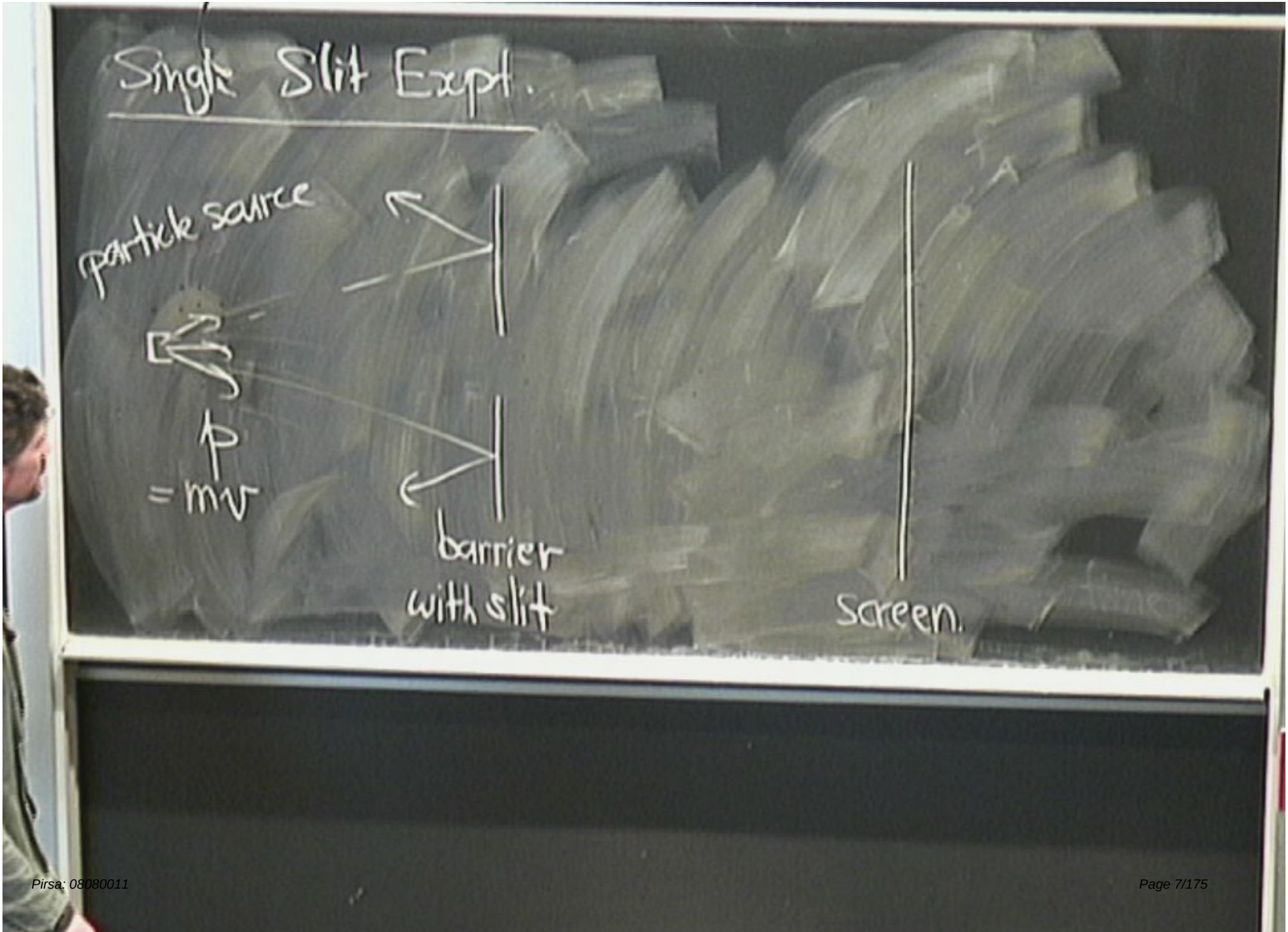
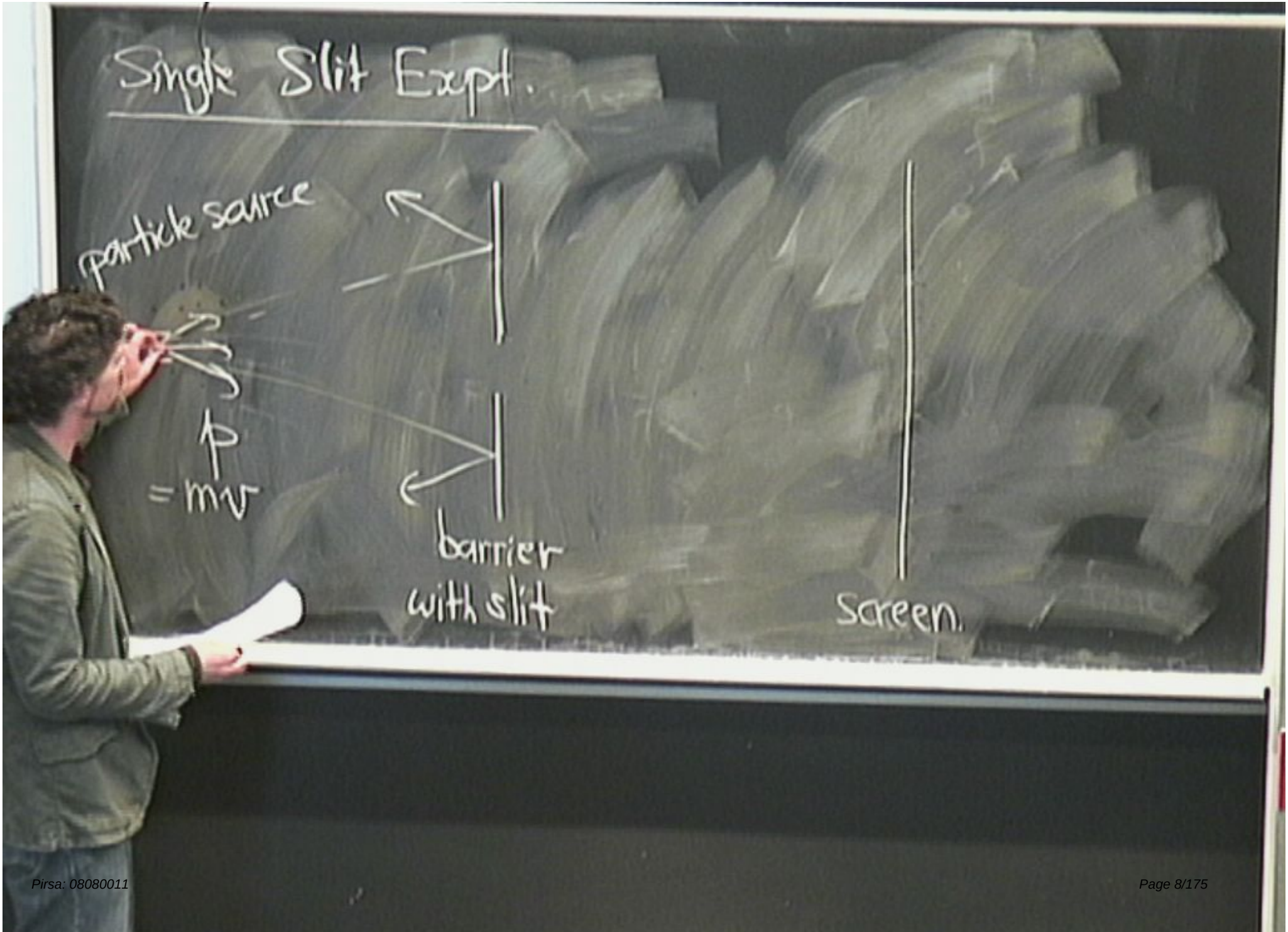
particle source


Single Slit Expt.
particle source
A

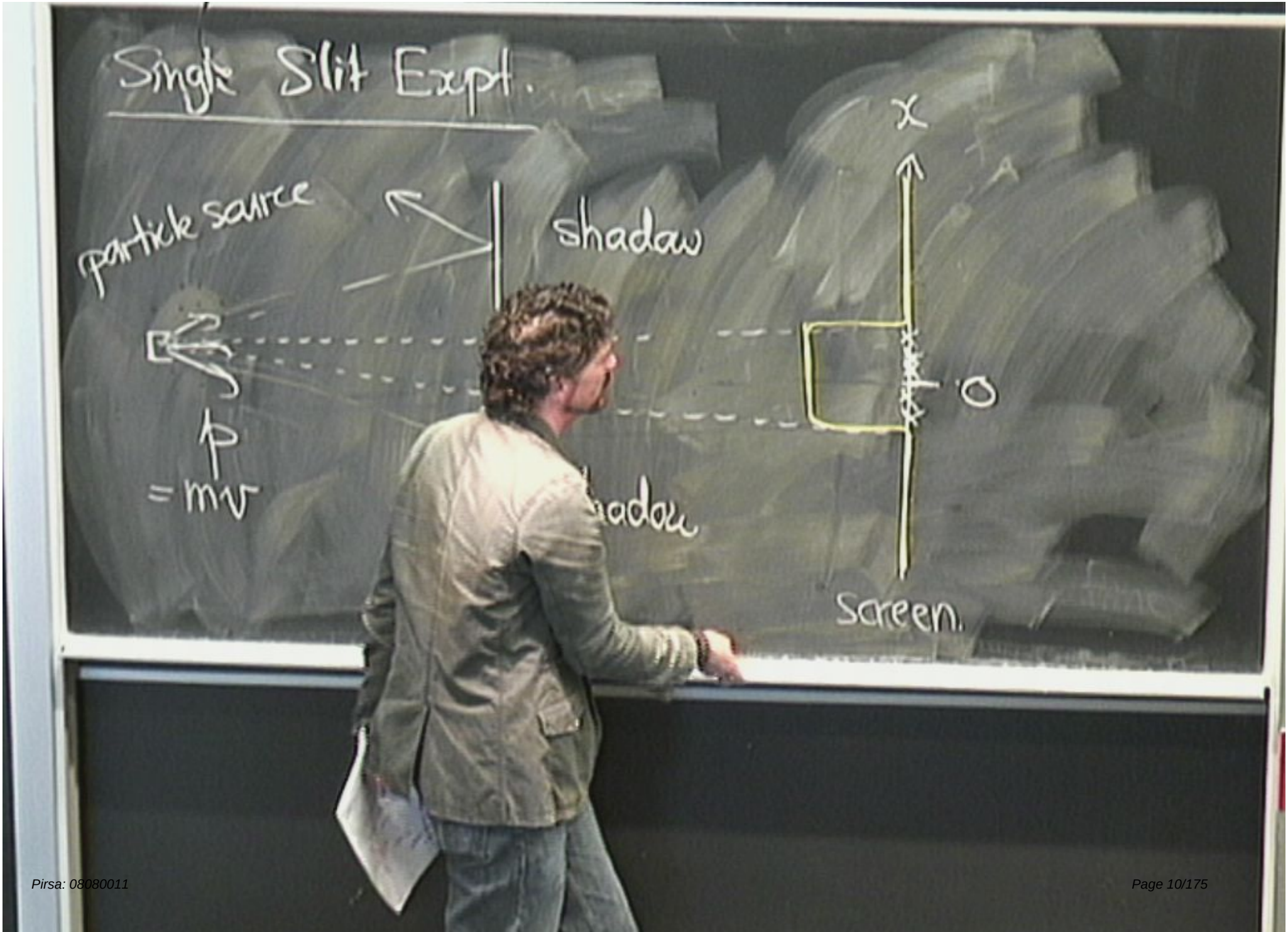

Single Slit Expt.
particle source
p
= mv

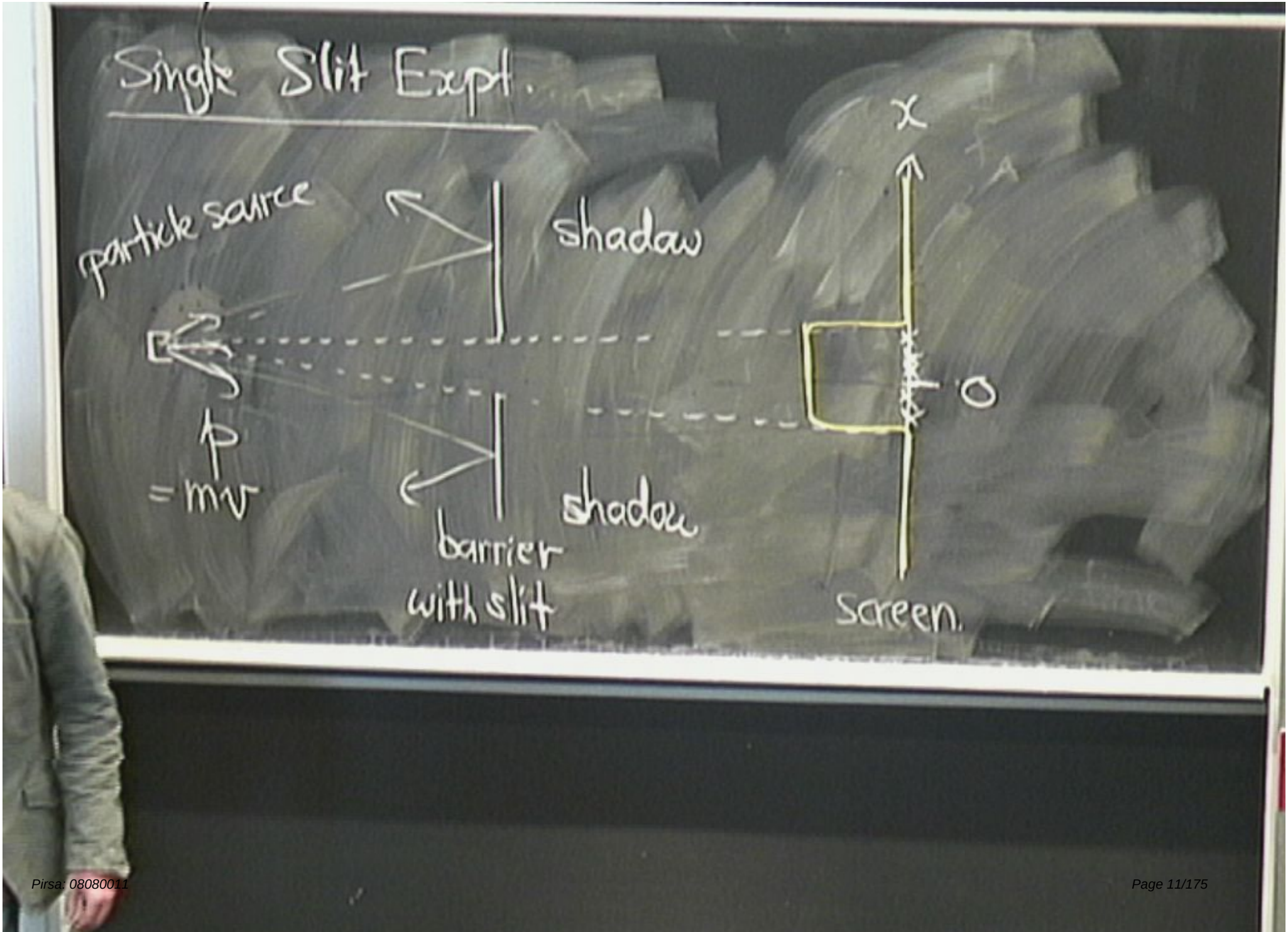

Single Slit Expt.
particle source
v
barrier
with slit

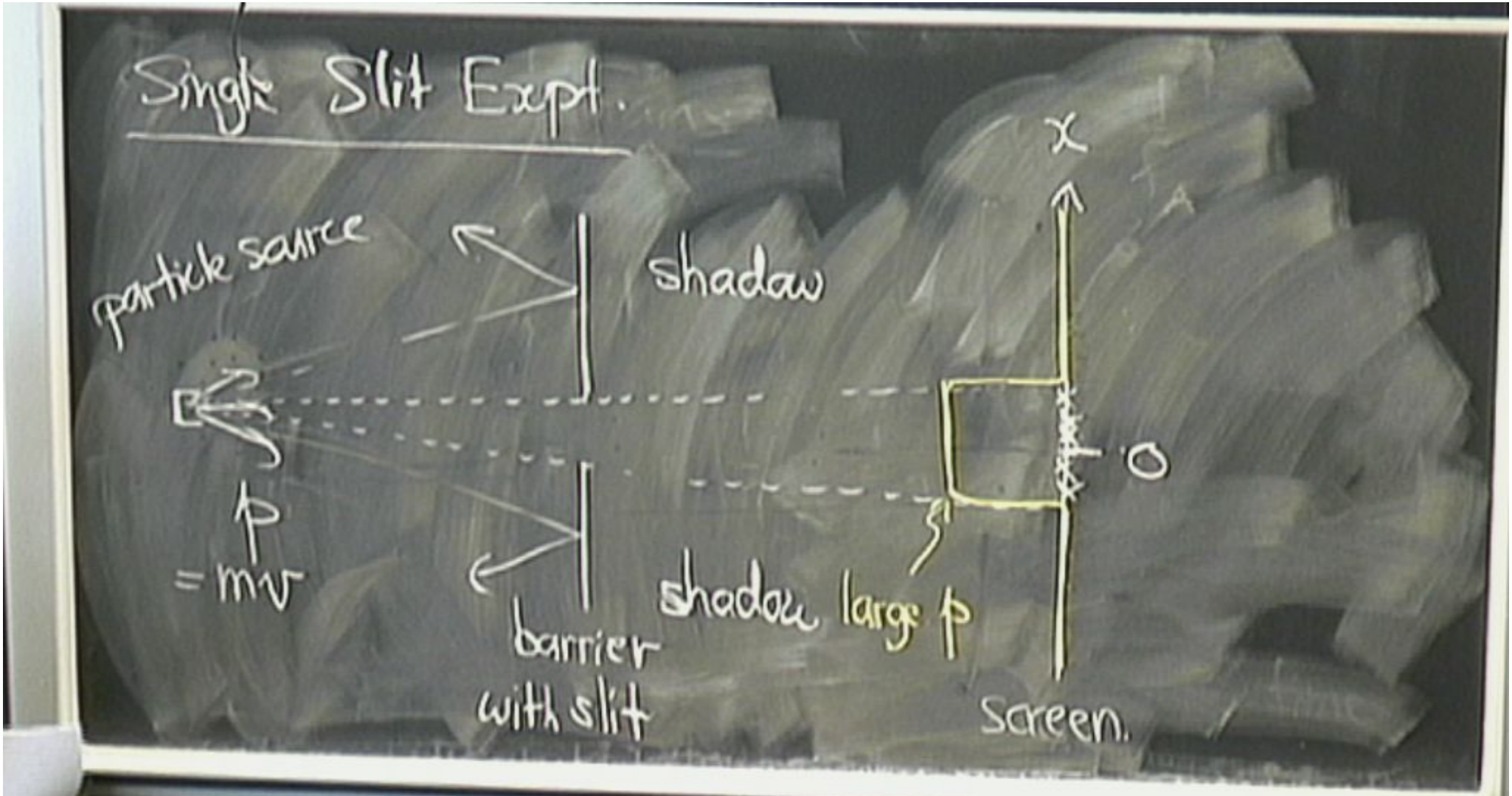

Single Slit Expt.
particle source
p
= mv
barrier
with slit
Screen.

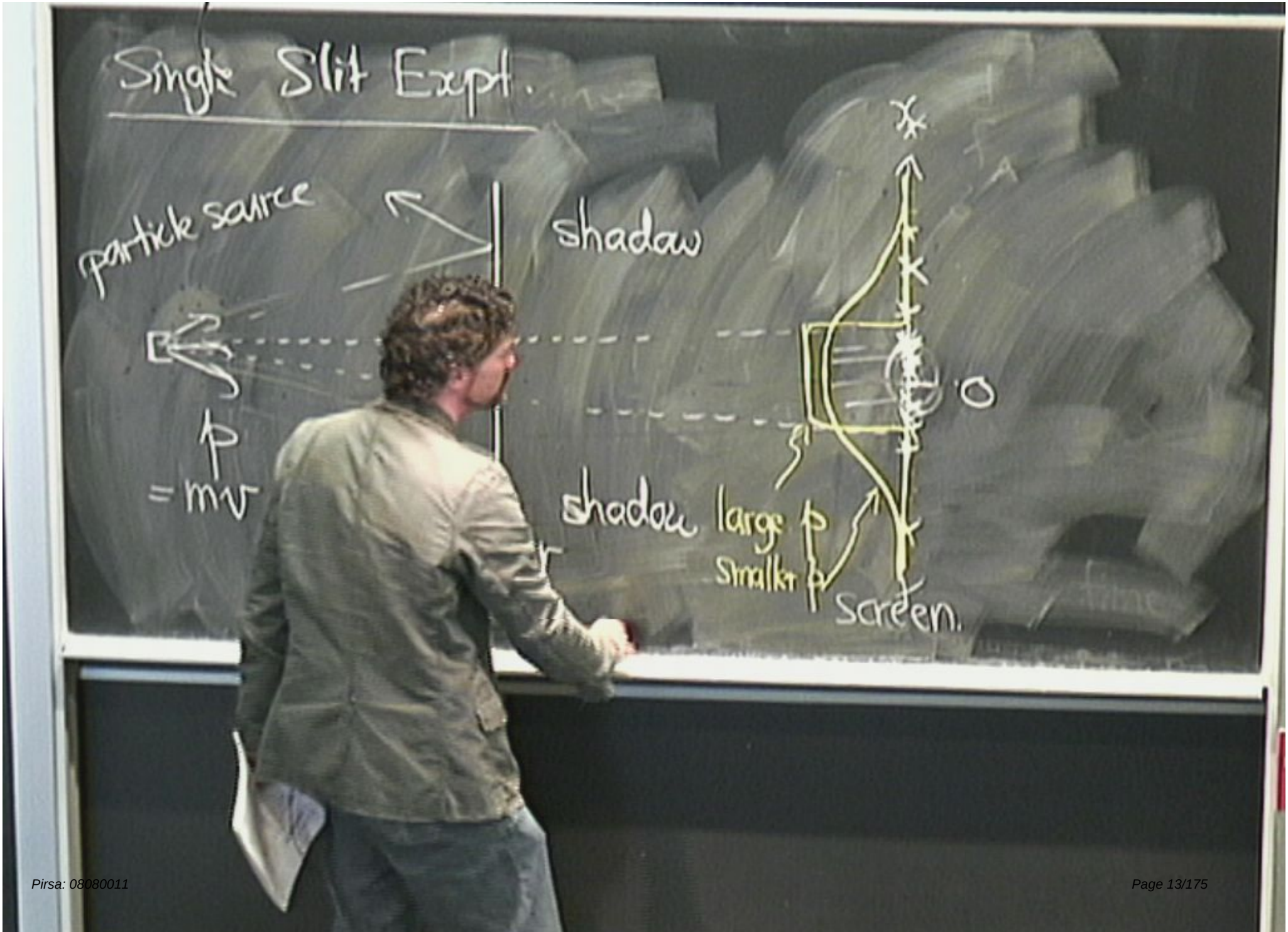

Single Slit Expt.
particle source
p
= mv
barrier
with slit
Screen.

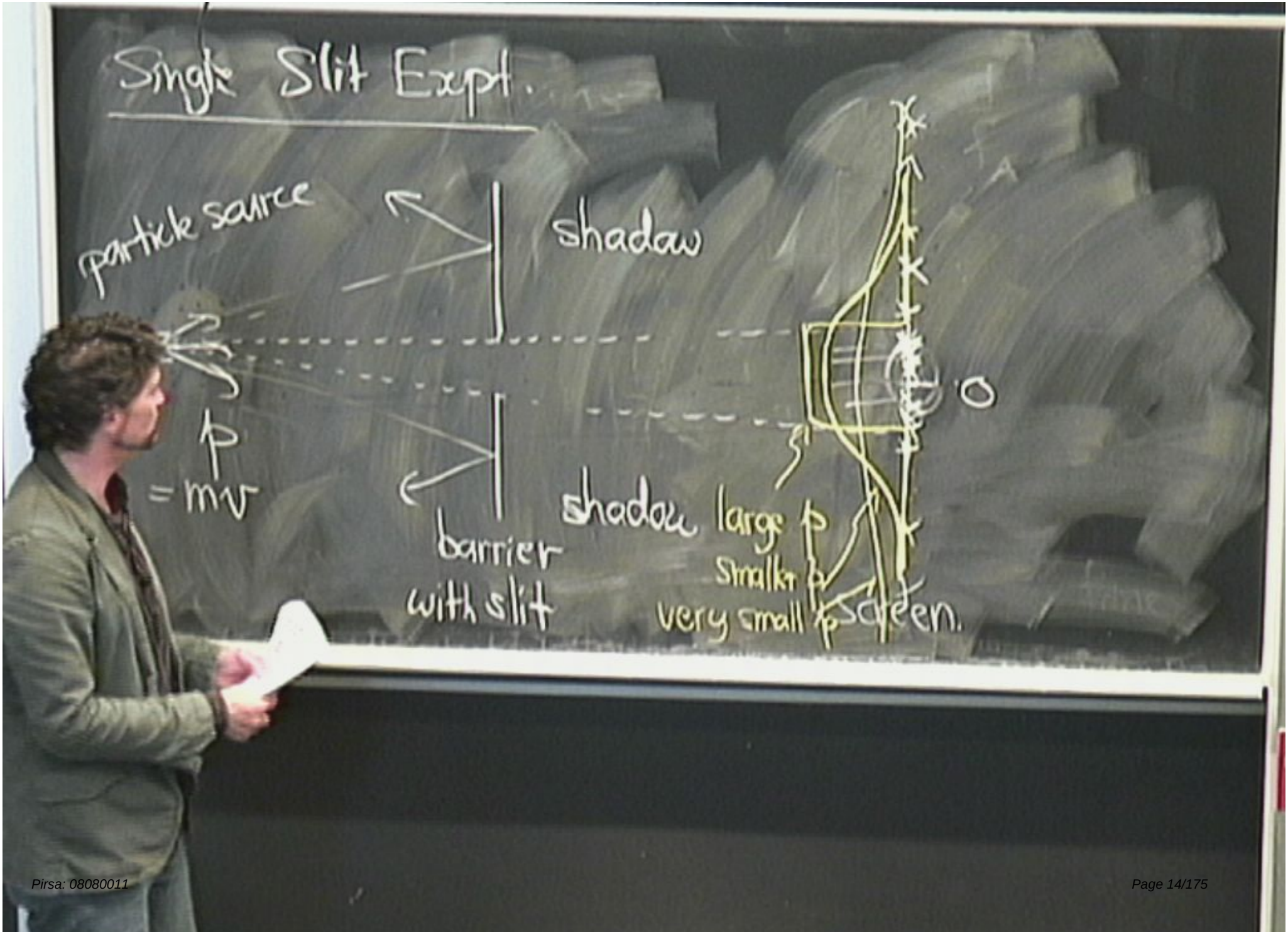

Single Slit Expt.
particle source
shadow
x
A
O
Screen.

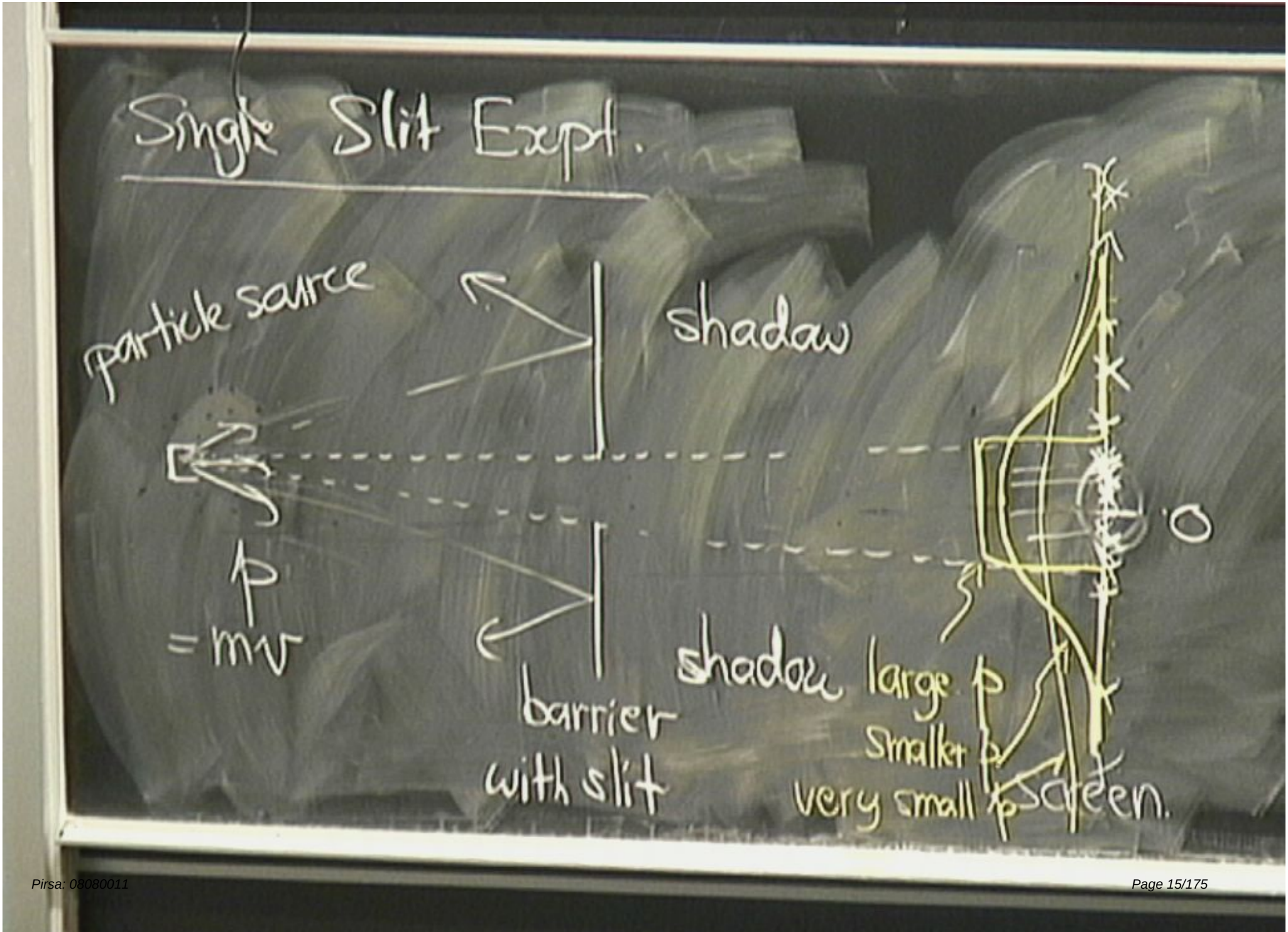

Single Slit Expt.
particle source
shadow
x
A
O
p
= mv
Screen.

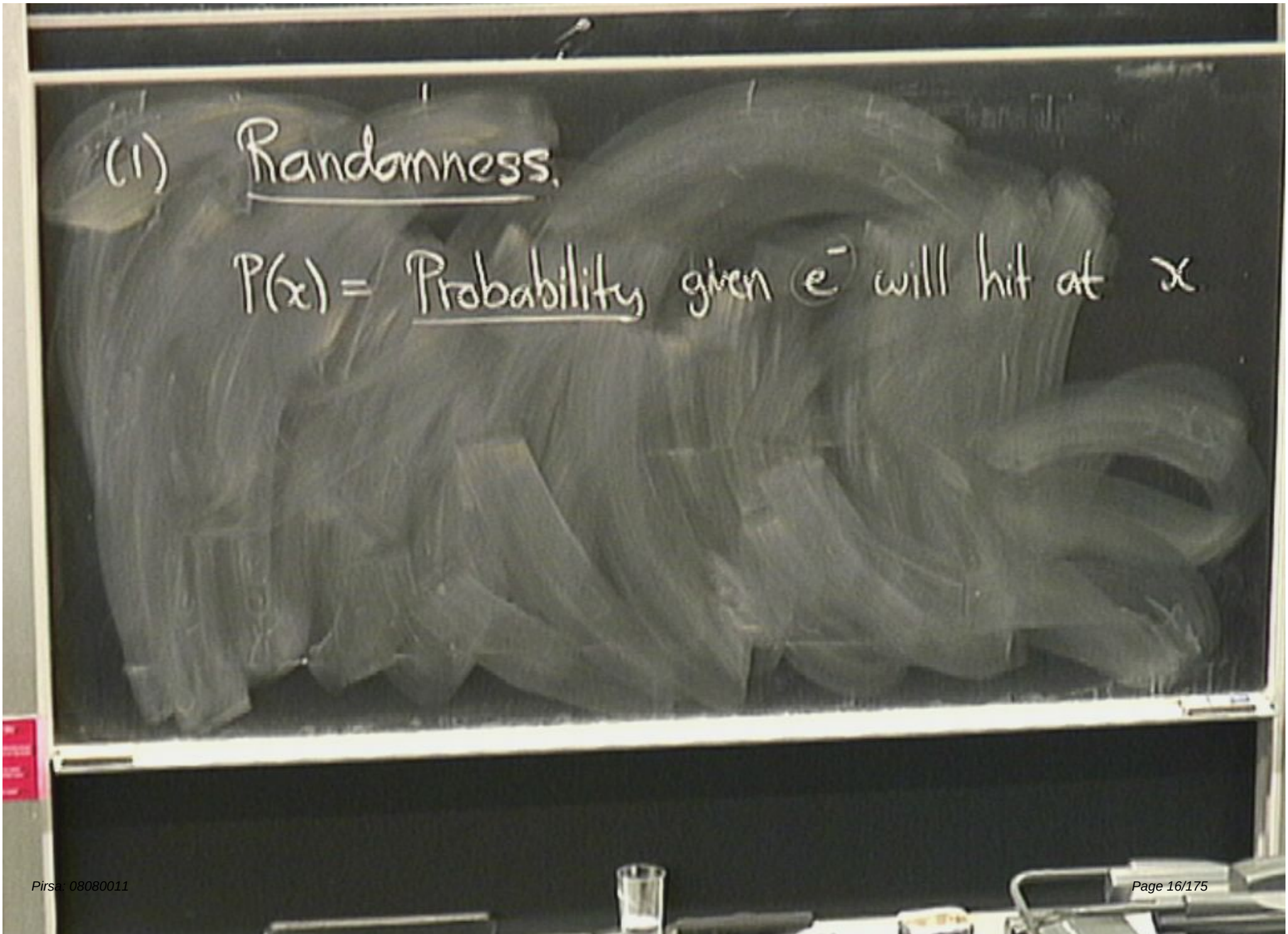

Single Slit Expt.
particle source
shadow
x
A
O
p
= mv
shadow
barrier
with slit
Screen.

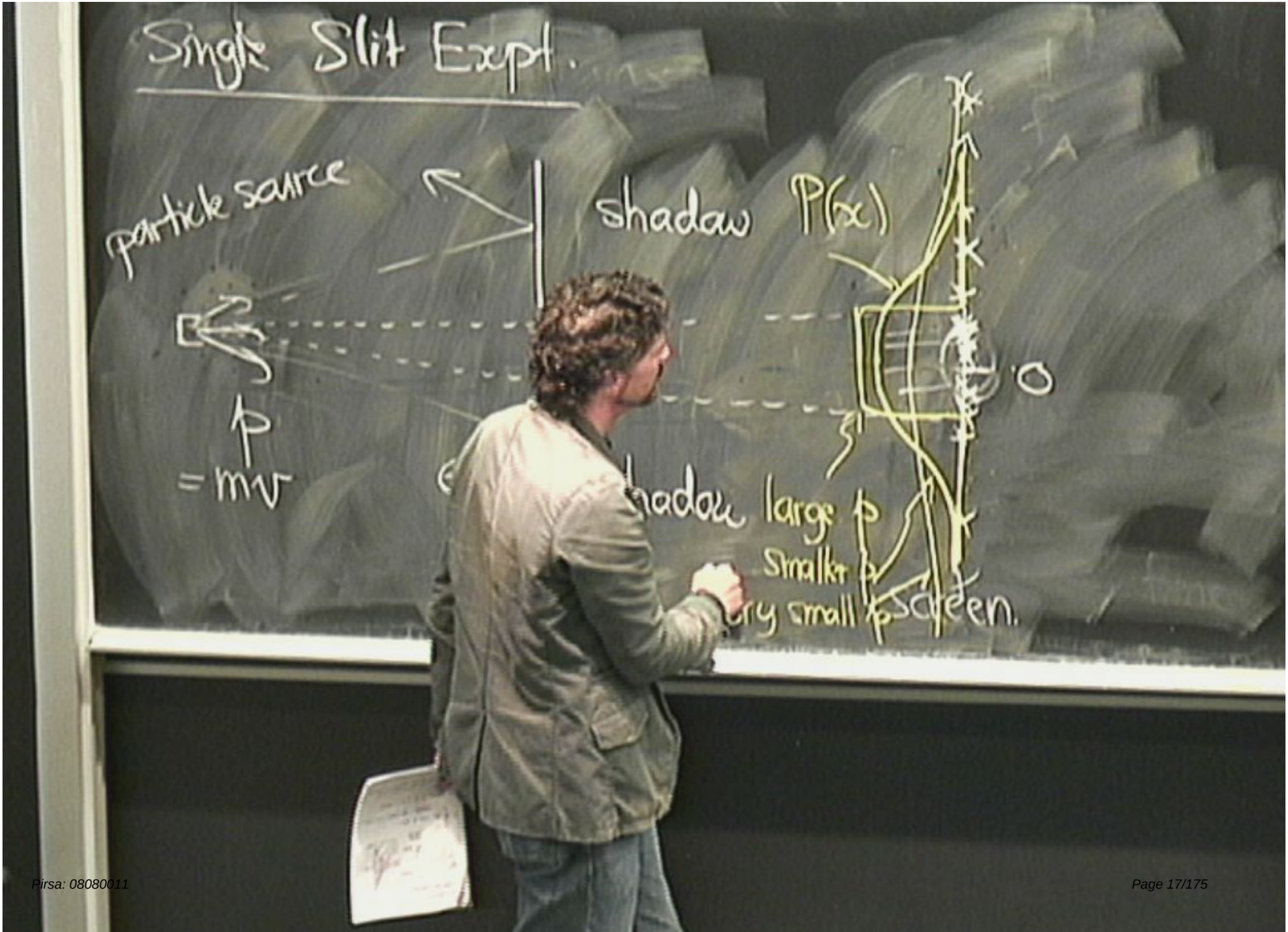

Single Slit Expt.
particle source
shadow
x
O
p
= mv
barrier
with slit
shadow
large p
Screen.


Single Slit Expt.
particle source
shadow
= mv
shadow large
smaller
Screen.
O


Single Slit Expt.
particle source
shadow
p
= mv
barrier
with slit
shadow
large p
Smaller p
very small p
screen.
O


Single Slit Expt.
particle source
shadow
p
= mv
barrier
with slit
shadow
large p
smaller p
very small p
screen.
O

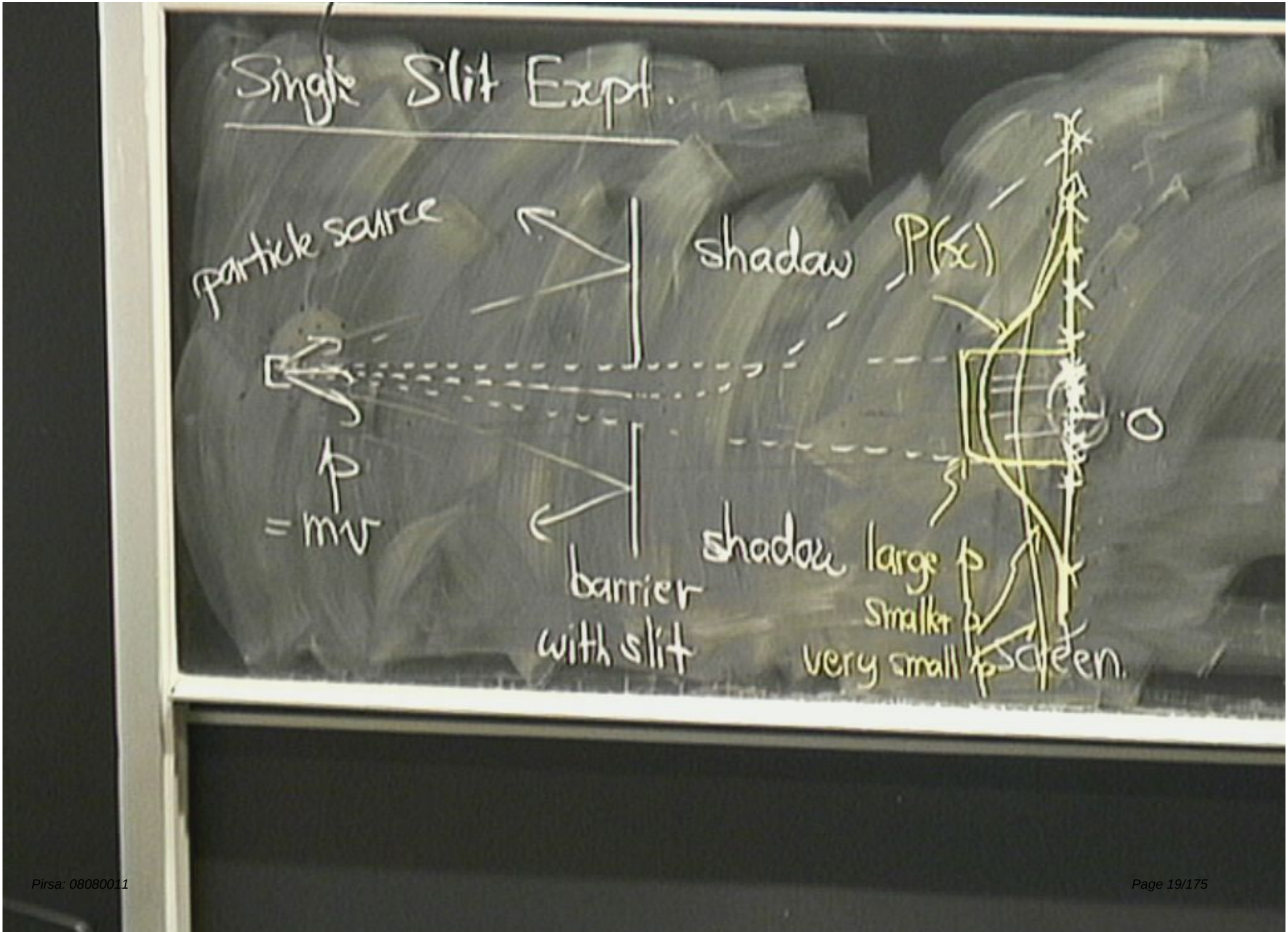

(1) Randomness.
P(x) = Probability given e⁻ will hit at x


Single Slit Expt.
particle source
shadow
P(x)
p
= mv
shadow large p
Smaller p
very small p
screen.

(1) Randomness.

$P(x)$ = Probability given e^- will hit at x

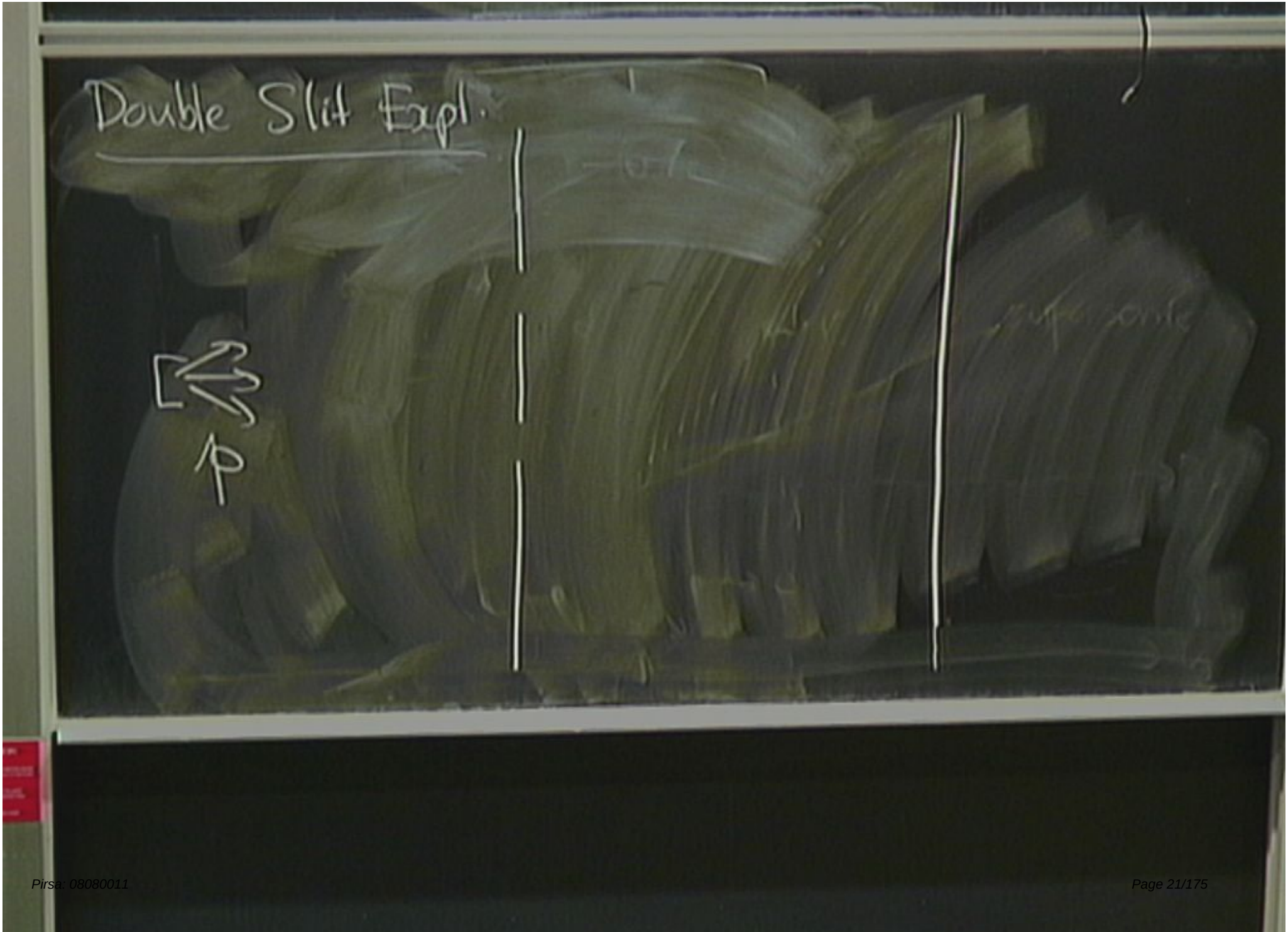
(2) Spreading (as ϕ is reduced)

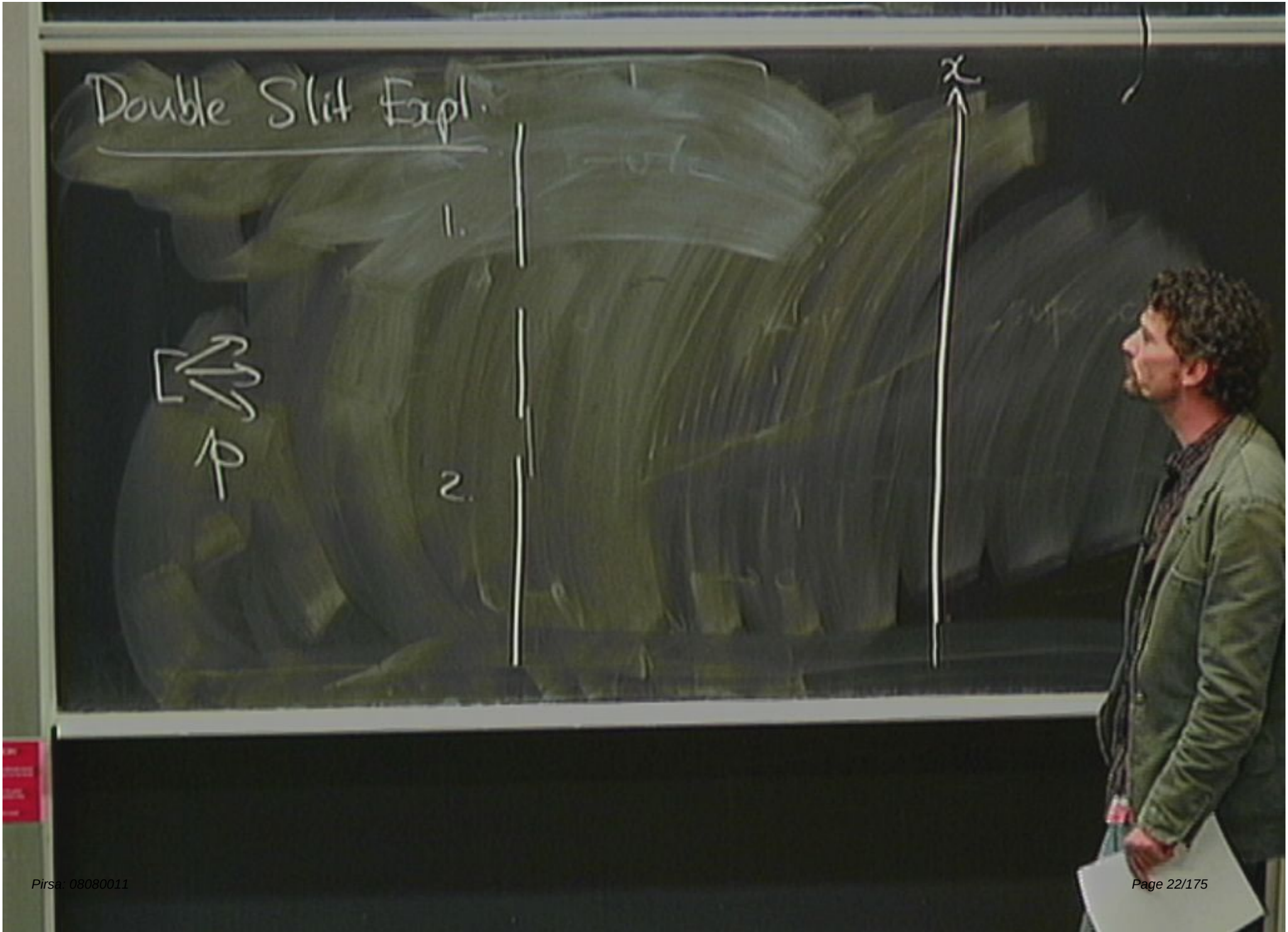

Single Slit Expt.
particle source
shadow
P(x)
0
p
= mv
barrier
with slit
shadow
large p
Smaller p
very small p
screen.

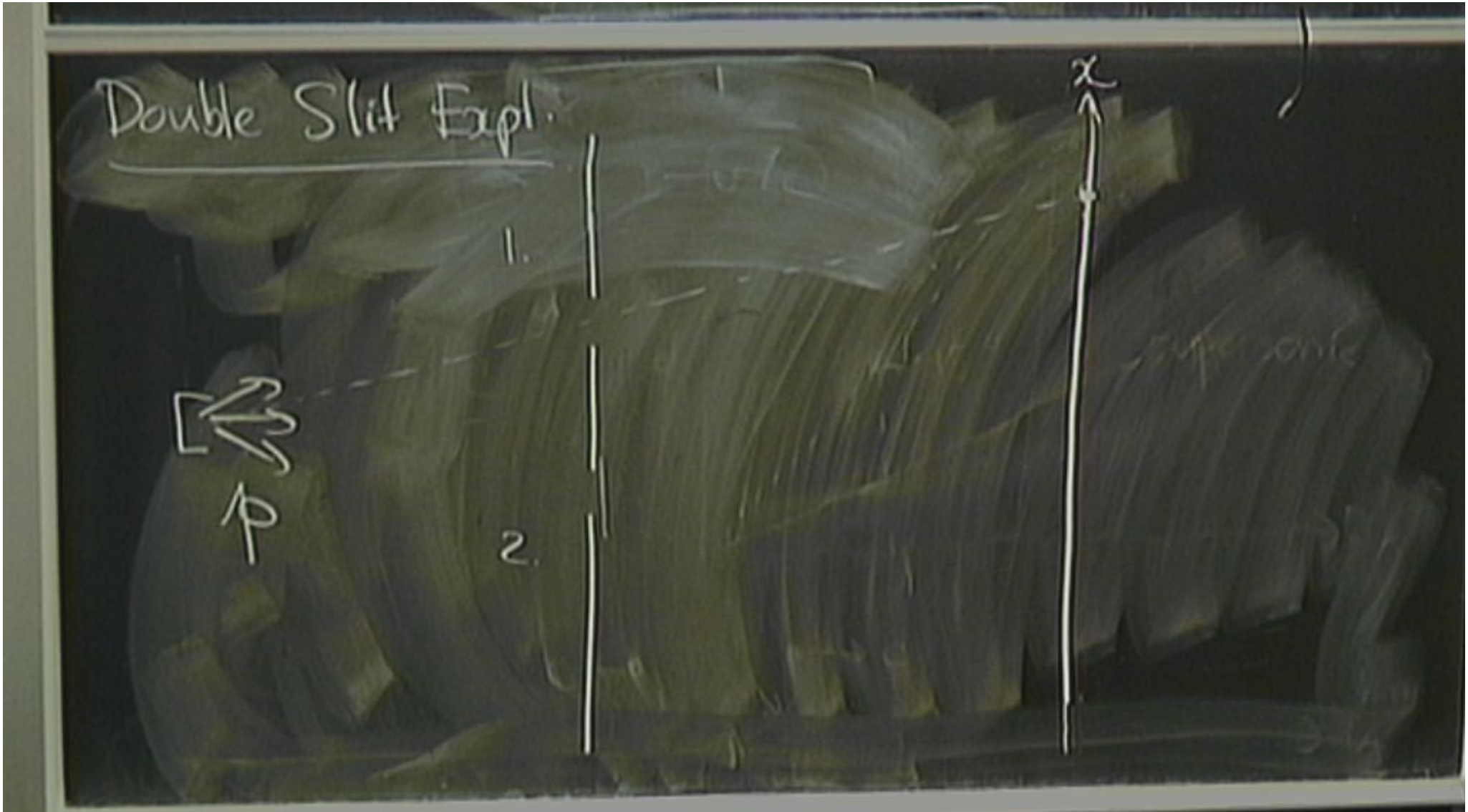
(1) Randomness.

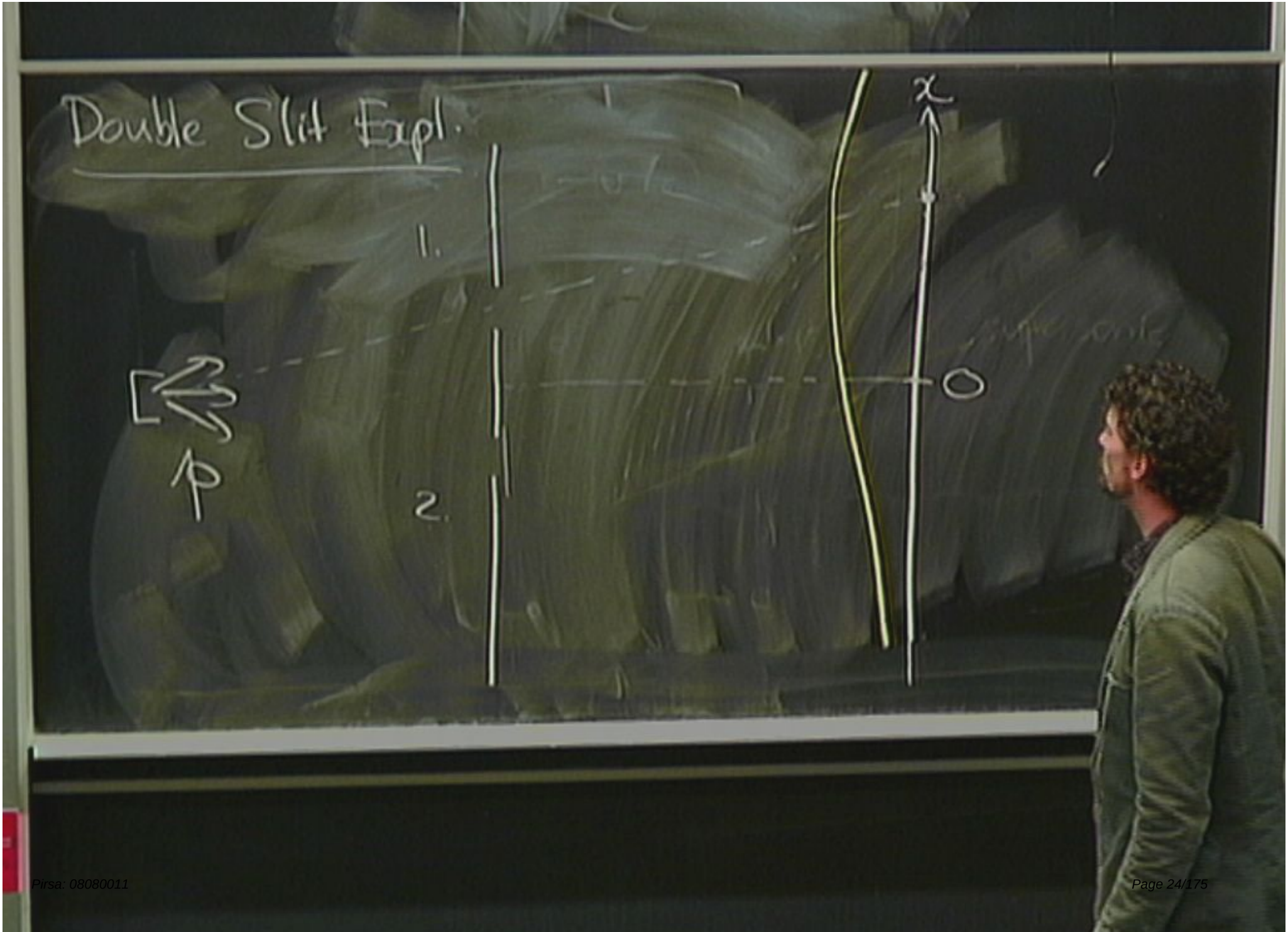
$P(x)$ = Probability given e^- will hit at x

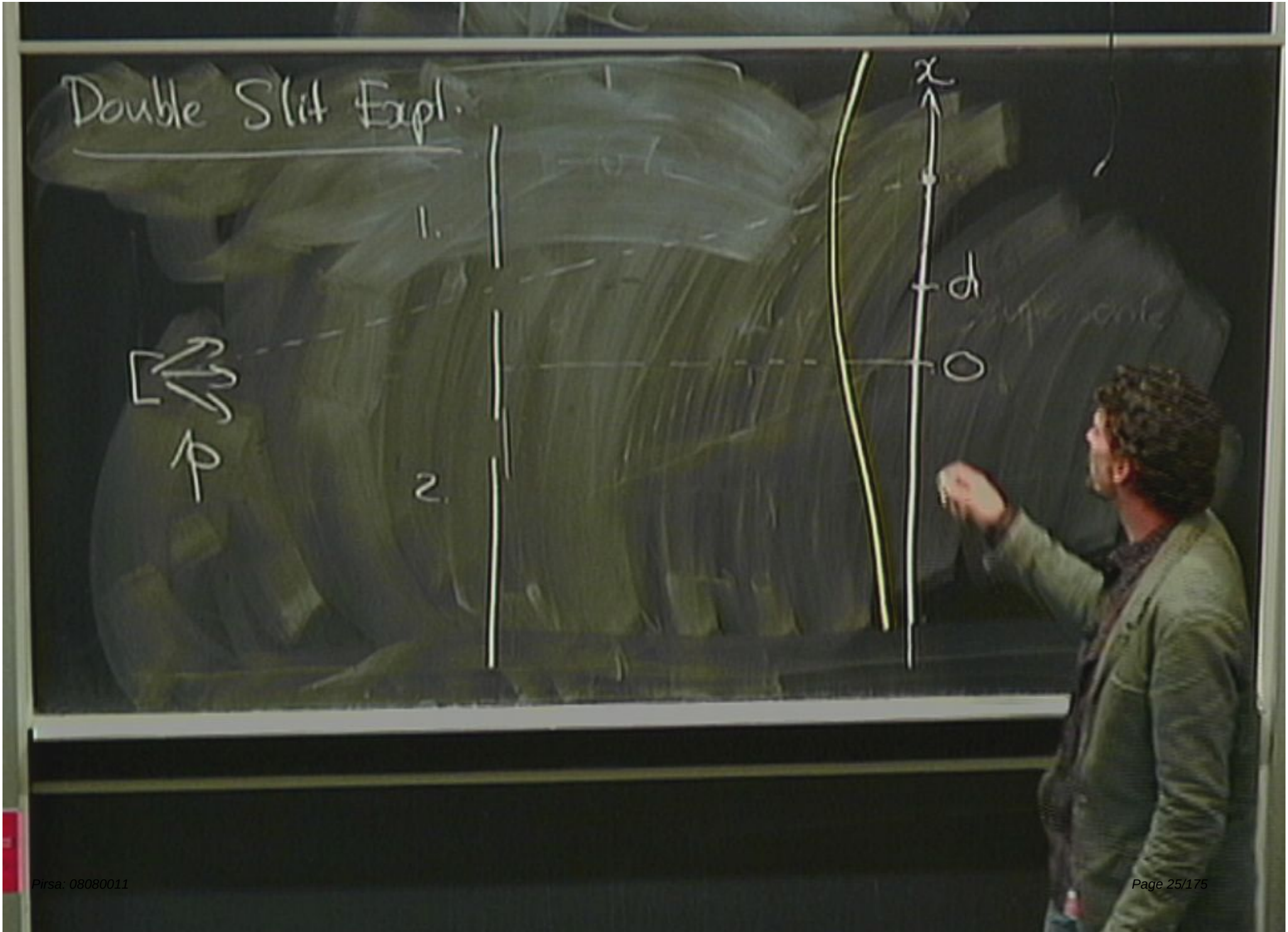
(2) Spreading (as ϕ is reduced)

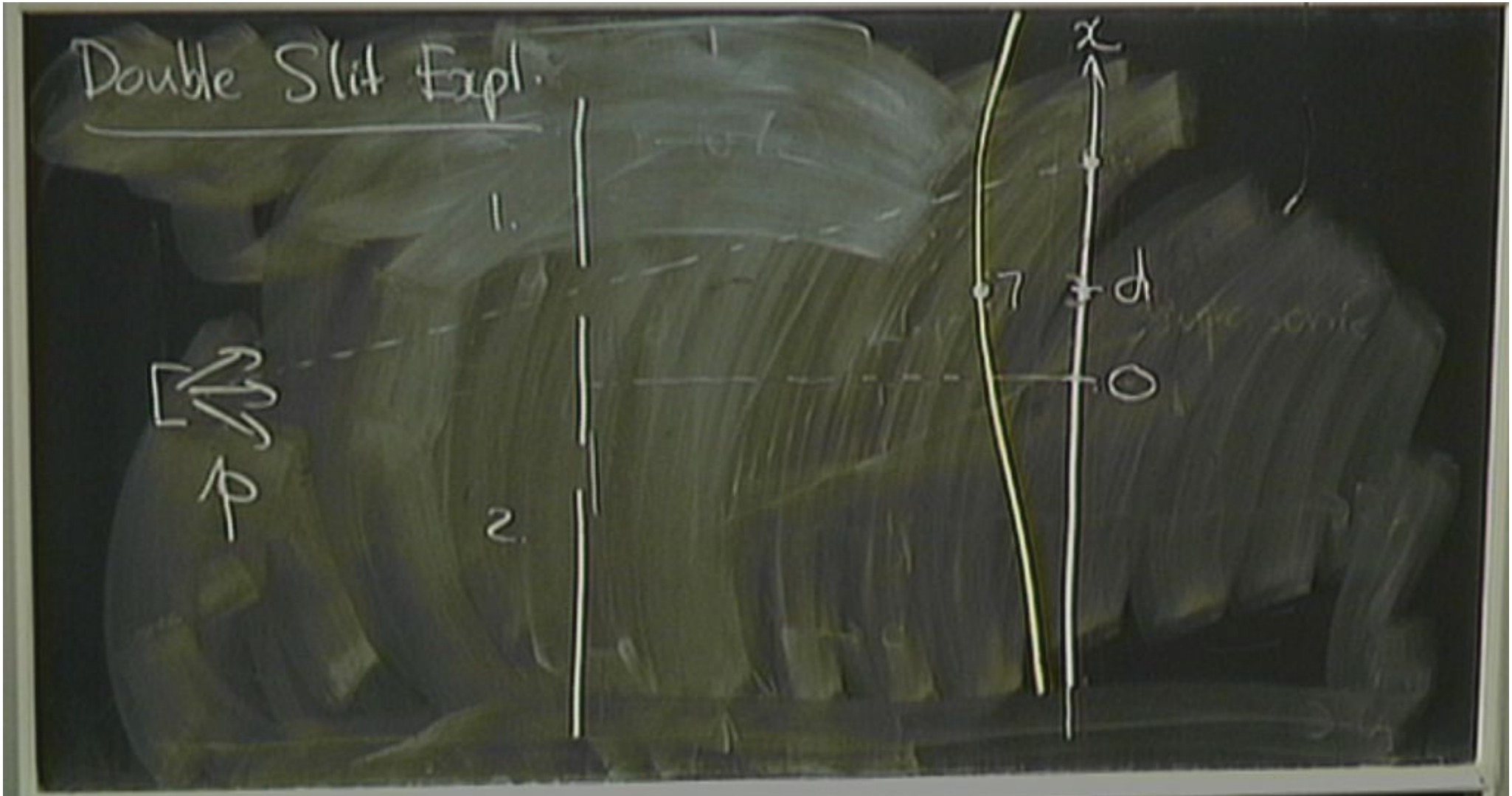

Double Slit Expl.
p

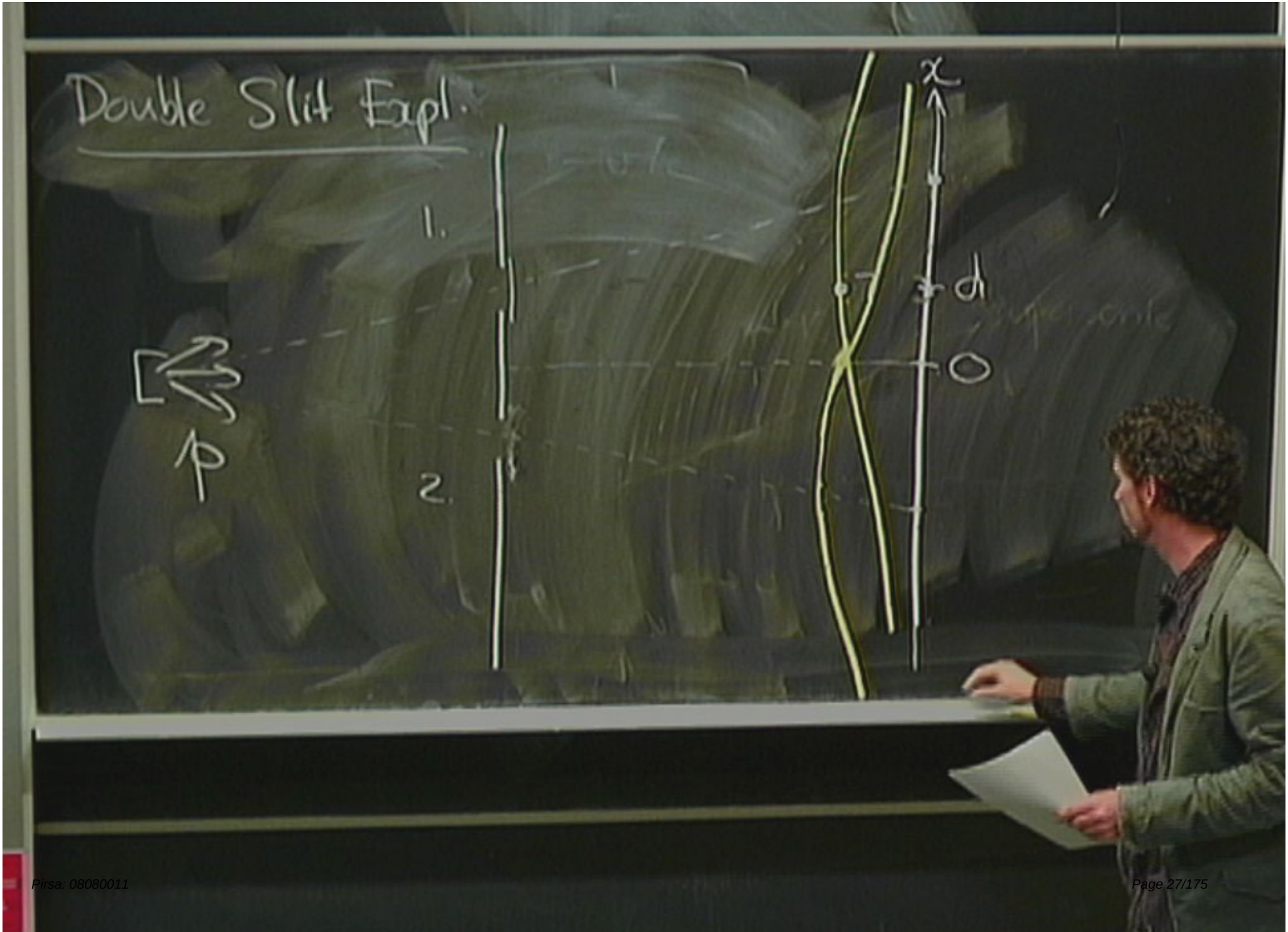

Double Slit Expl.
1.
2.
x

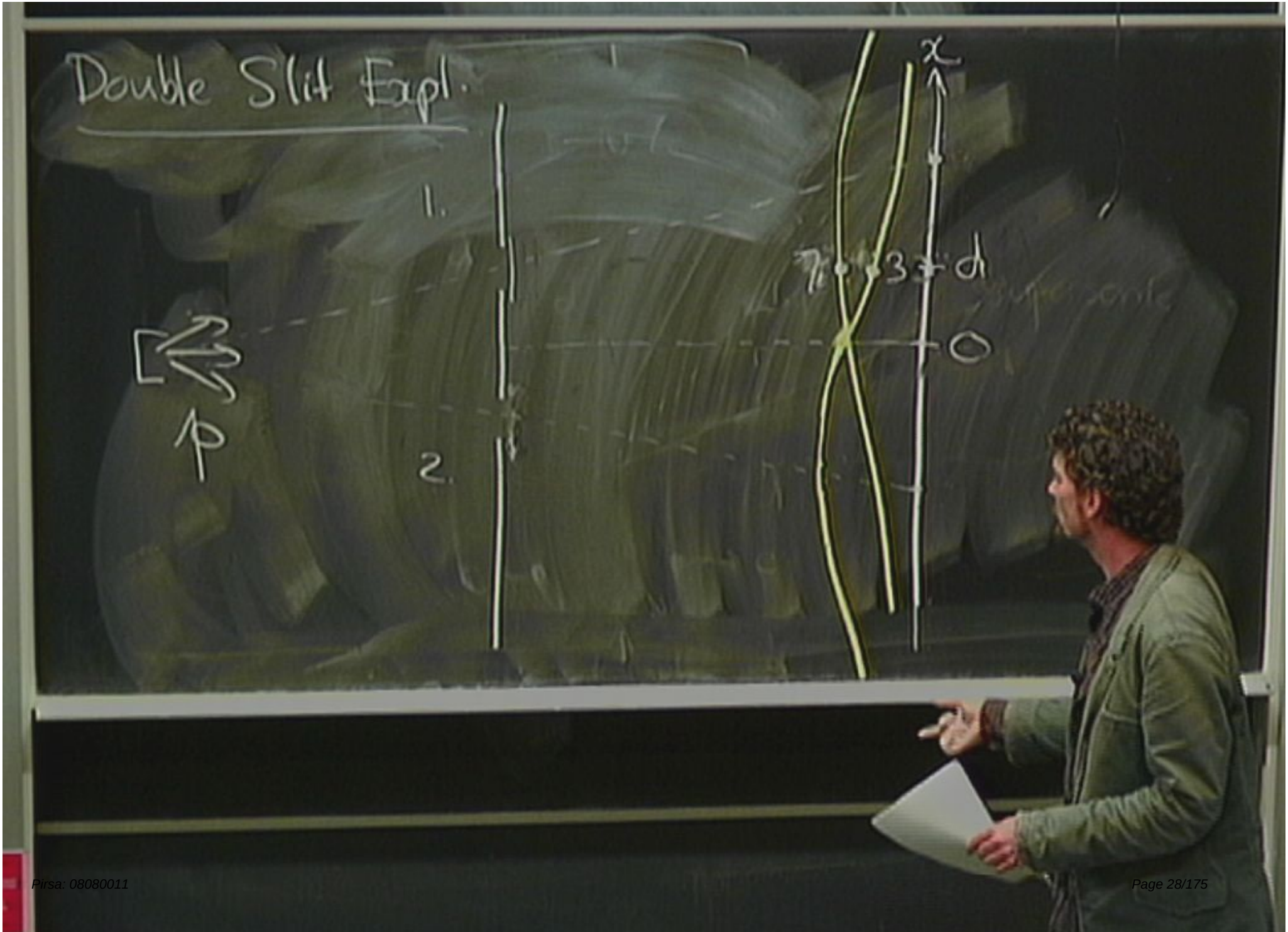

Double Slit Expl.
x
1.
2.
p

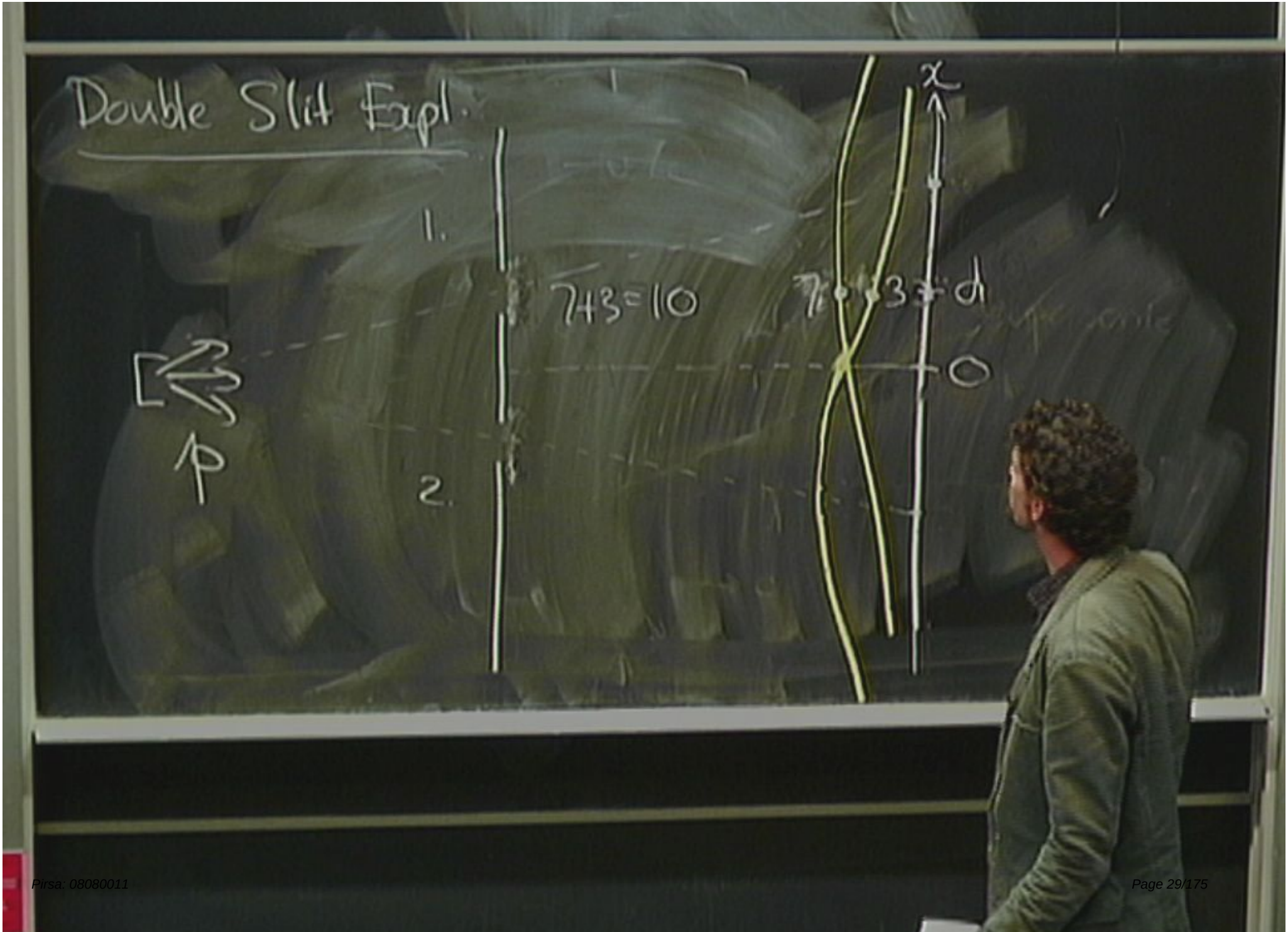

Double Slit Expl.
1.
2.
x
0
p

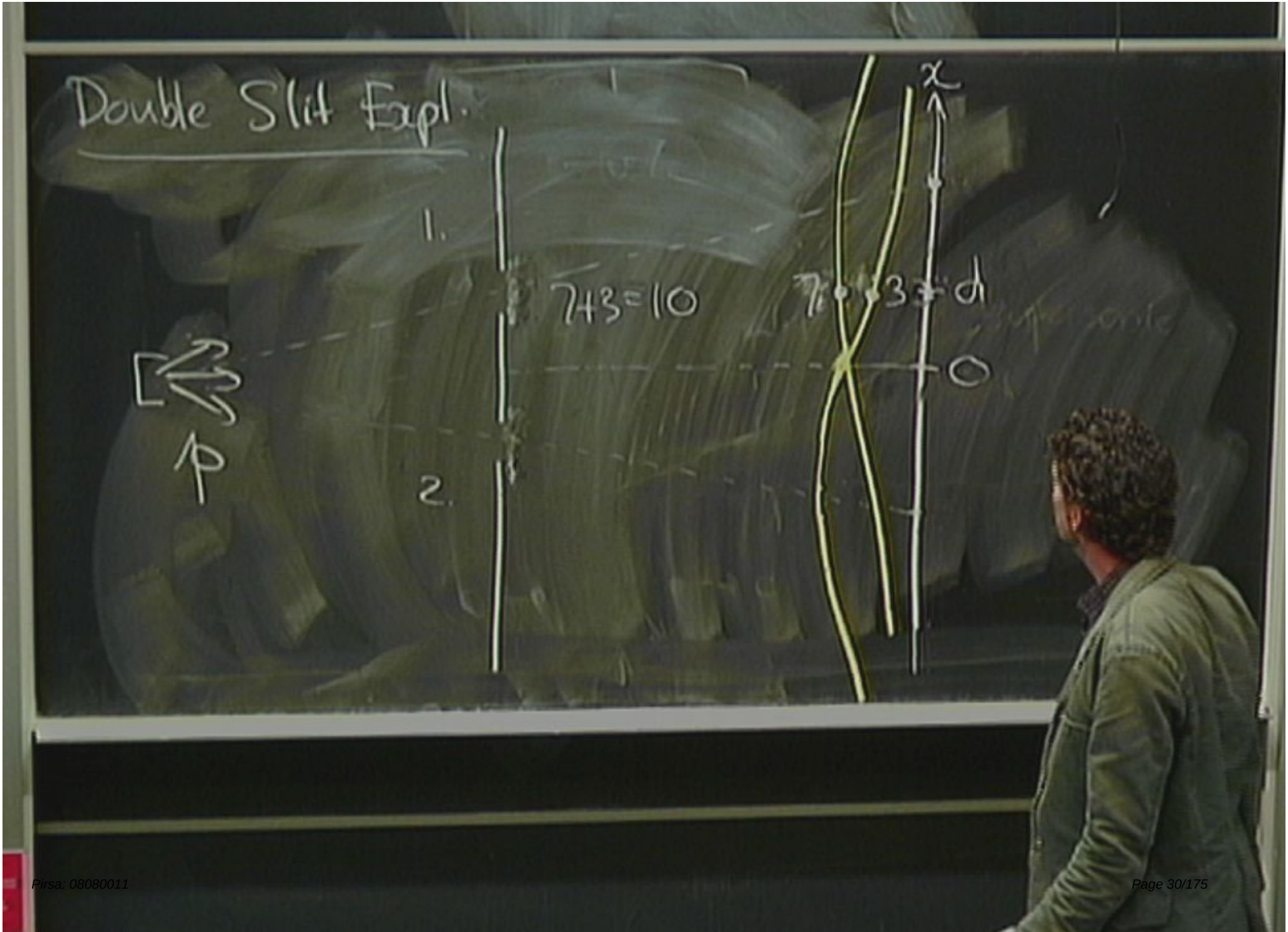

Double Slit Expl.
1.
2.
x
d
0
p

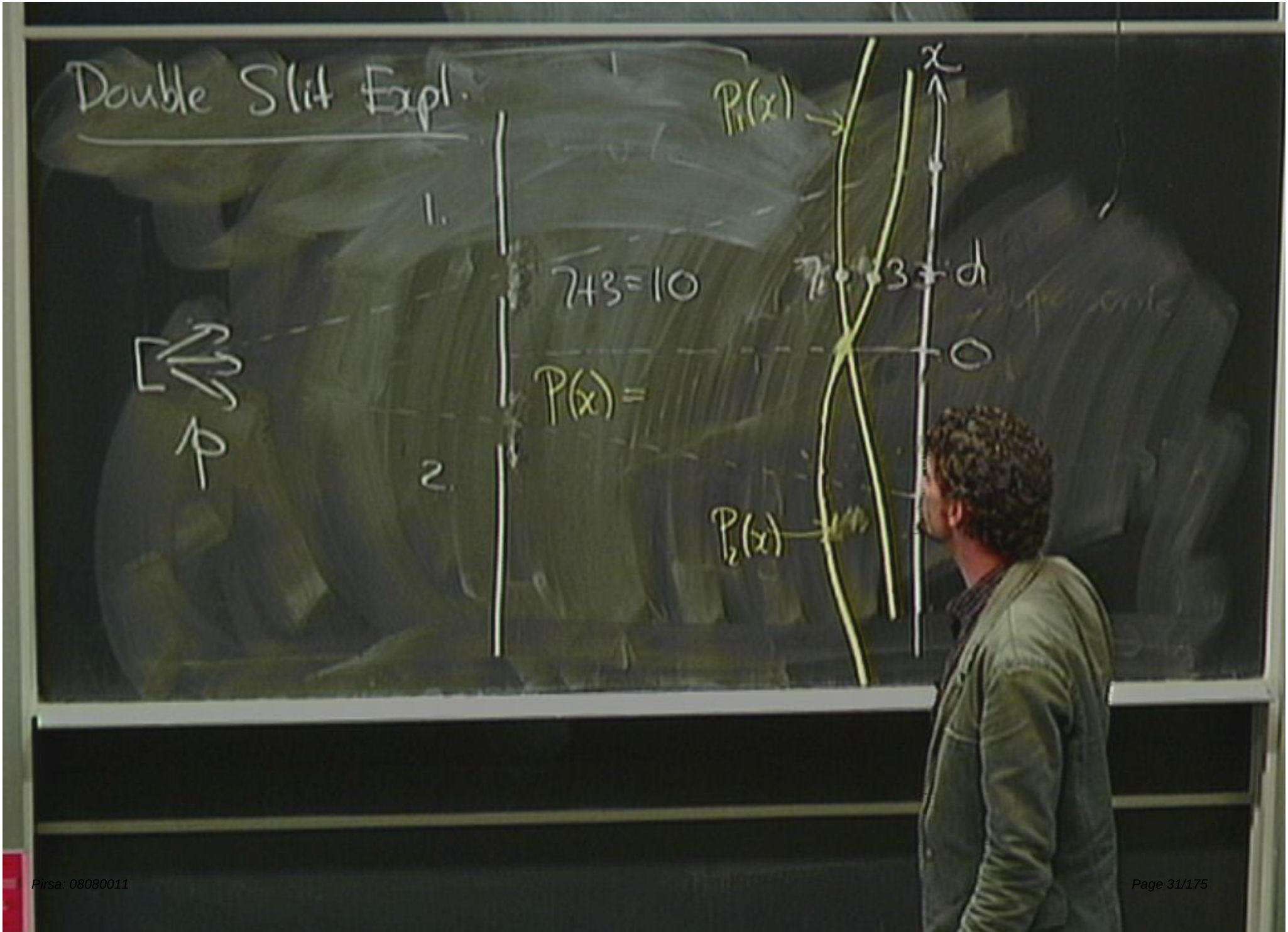

Double Slit Expl.
1.
2.
x
d
0

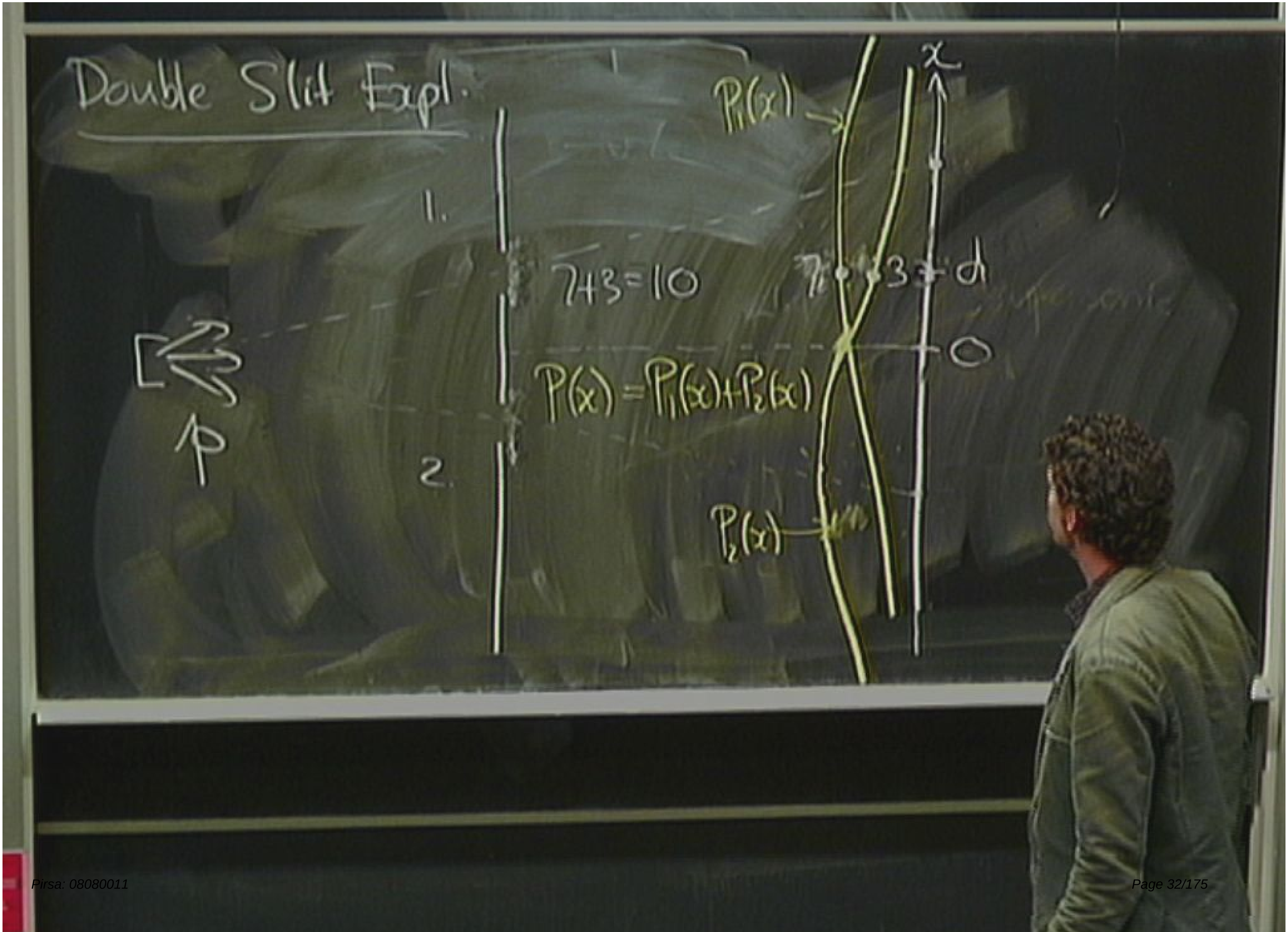

Double Slit Expl.
1.
2.
x
d
0

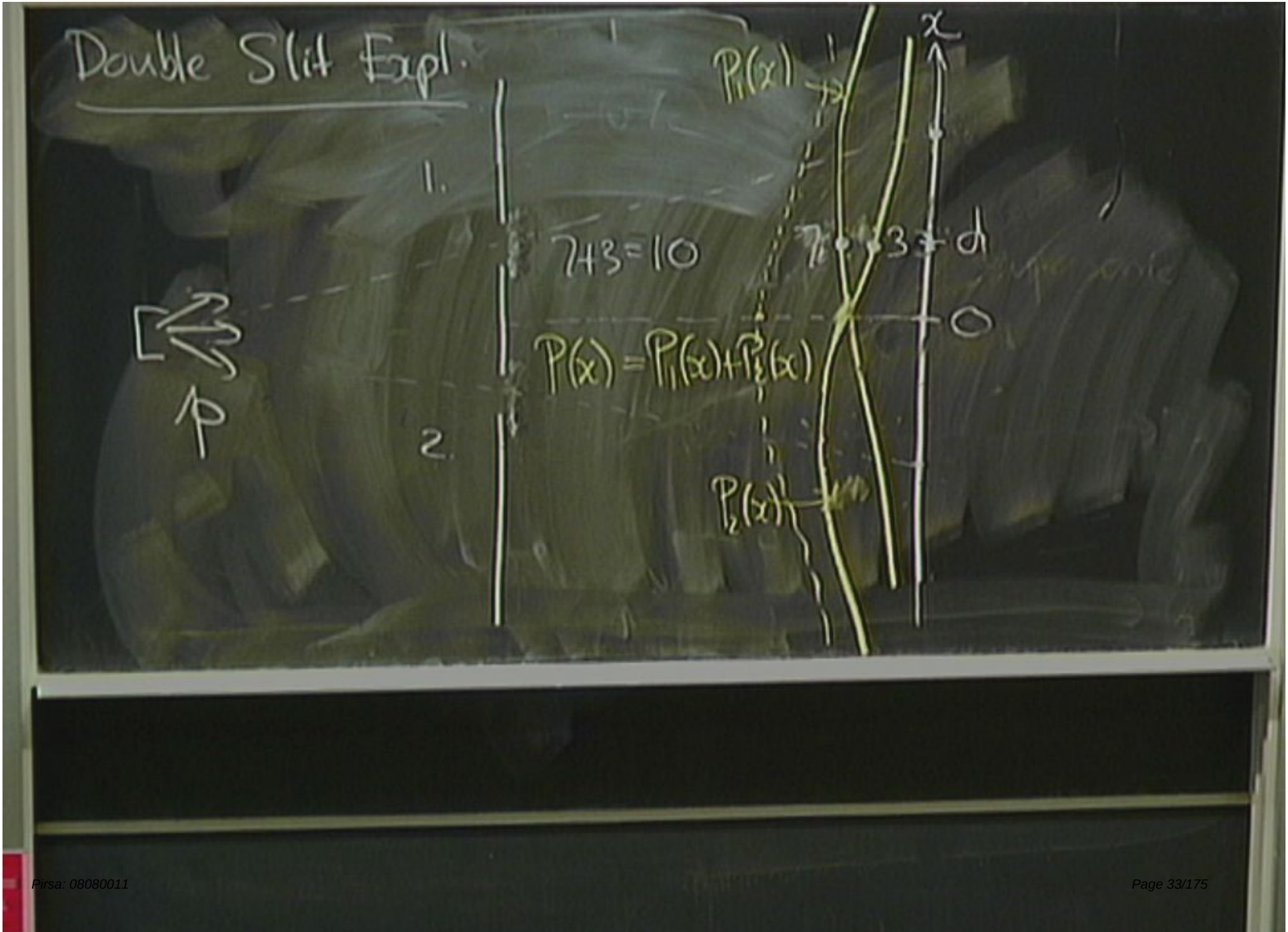

Double Slit Expl.
1.
2.
x
3
0

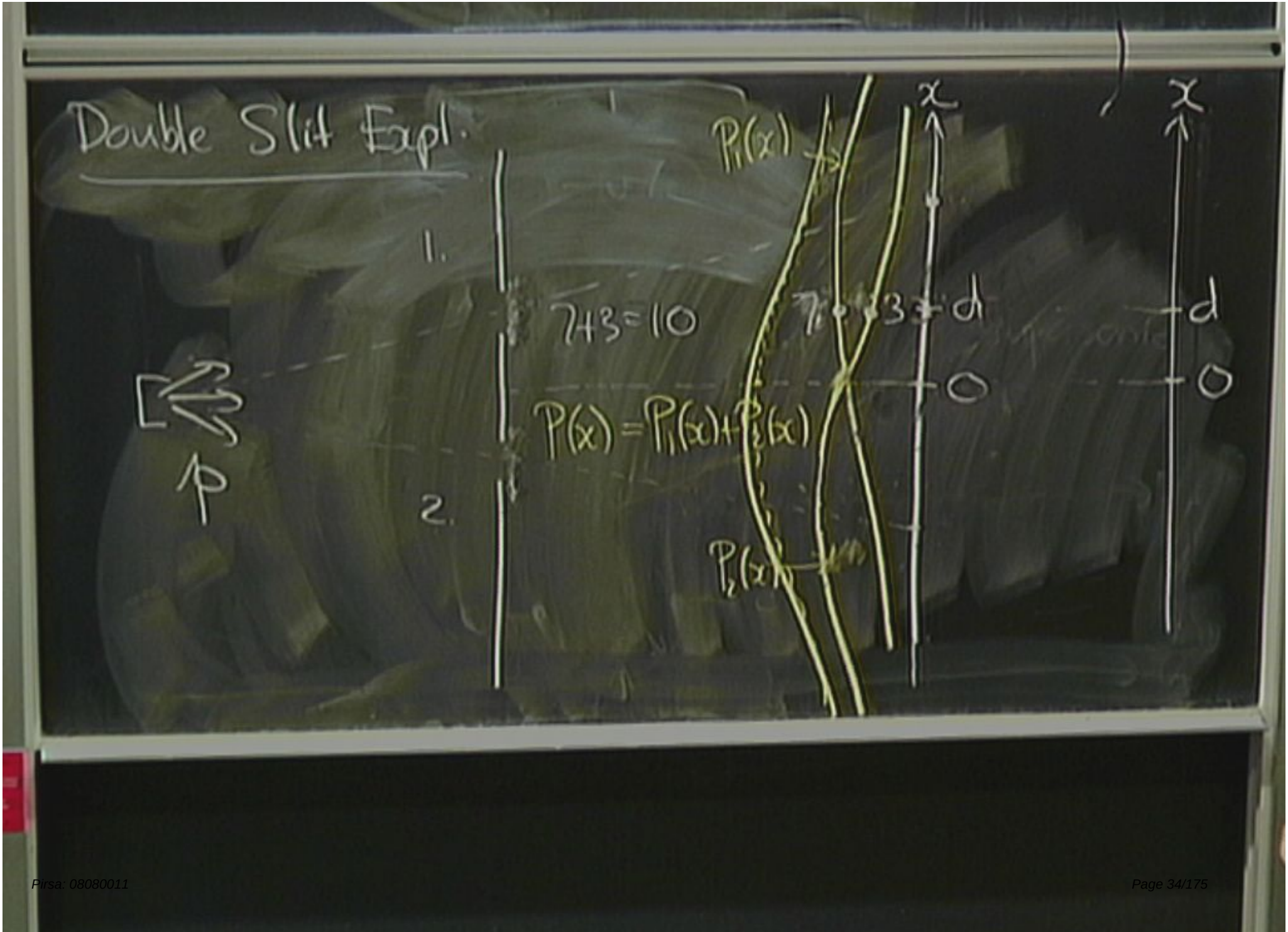

Double Slit Expl.
1.
2.
x
O

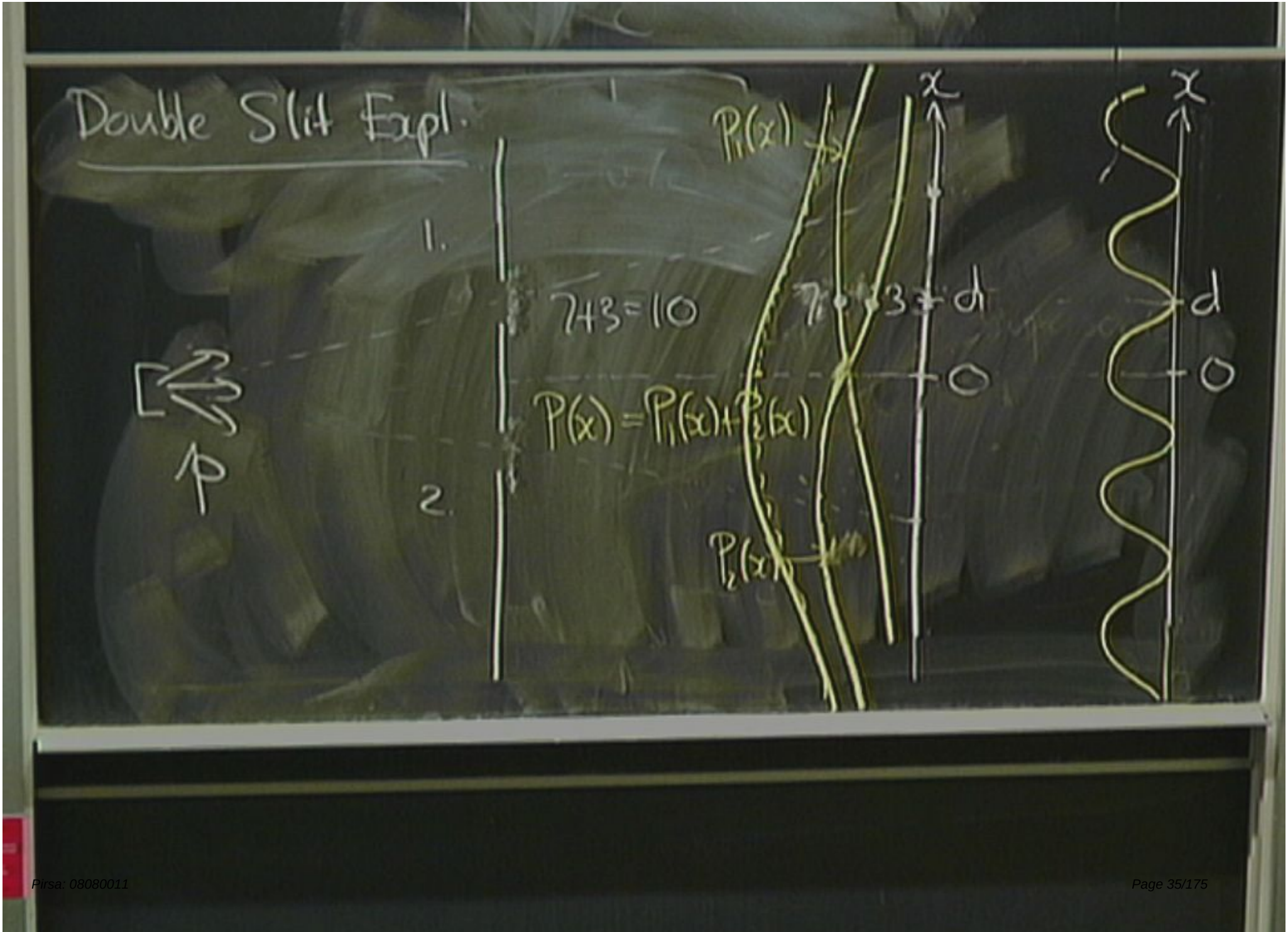

Double Slit Expl.
1.
2.
P
O
x

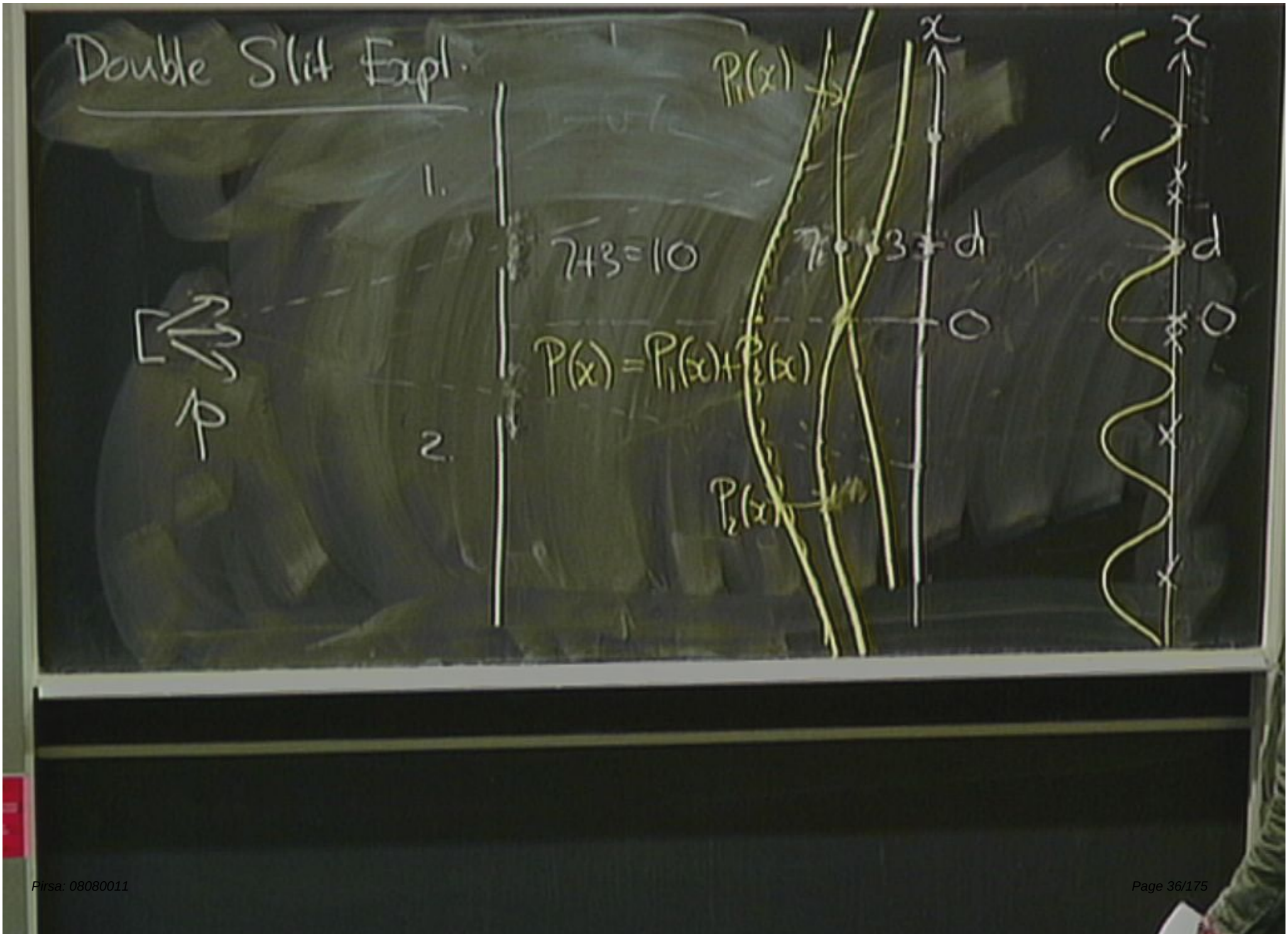

Double Slit Expl.
P1(x)
x
1.
7+3=10
7+3=d
0
P(x)=
P
2.
P2(x)

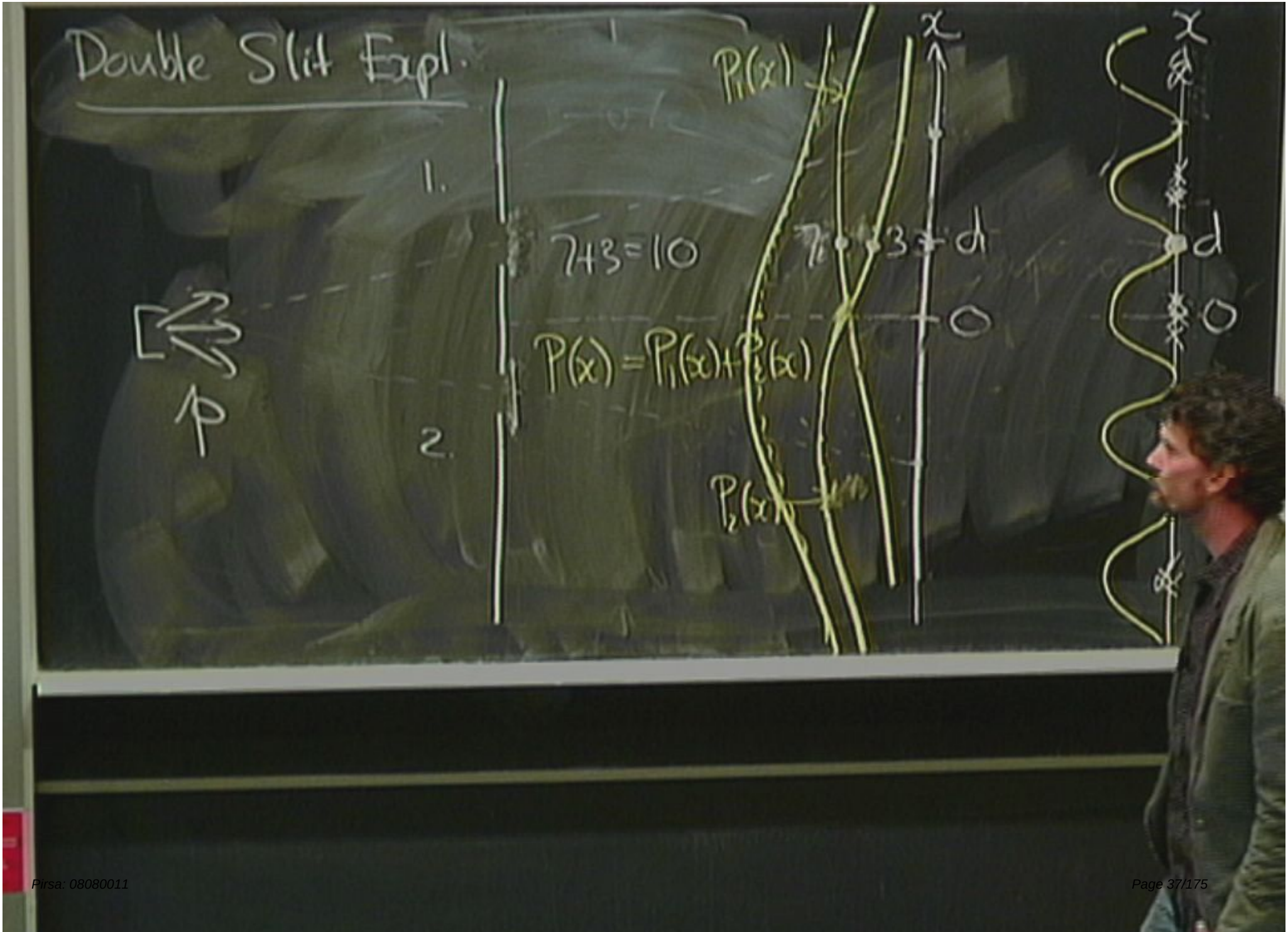

Double Slit Expl.
1.
2.
7+3=10
$P(x) = P_1(x) + P_2(x)$
$P_1(x)$
$P_2(x)$
x
d
0
p

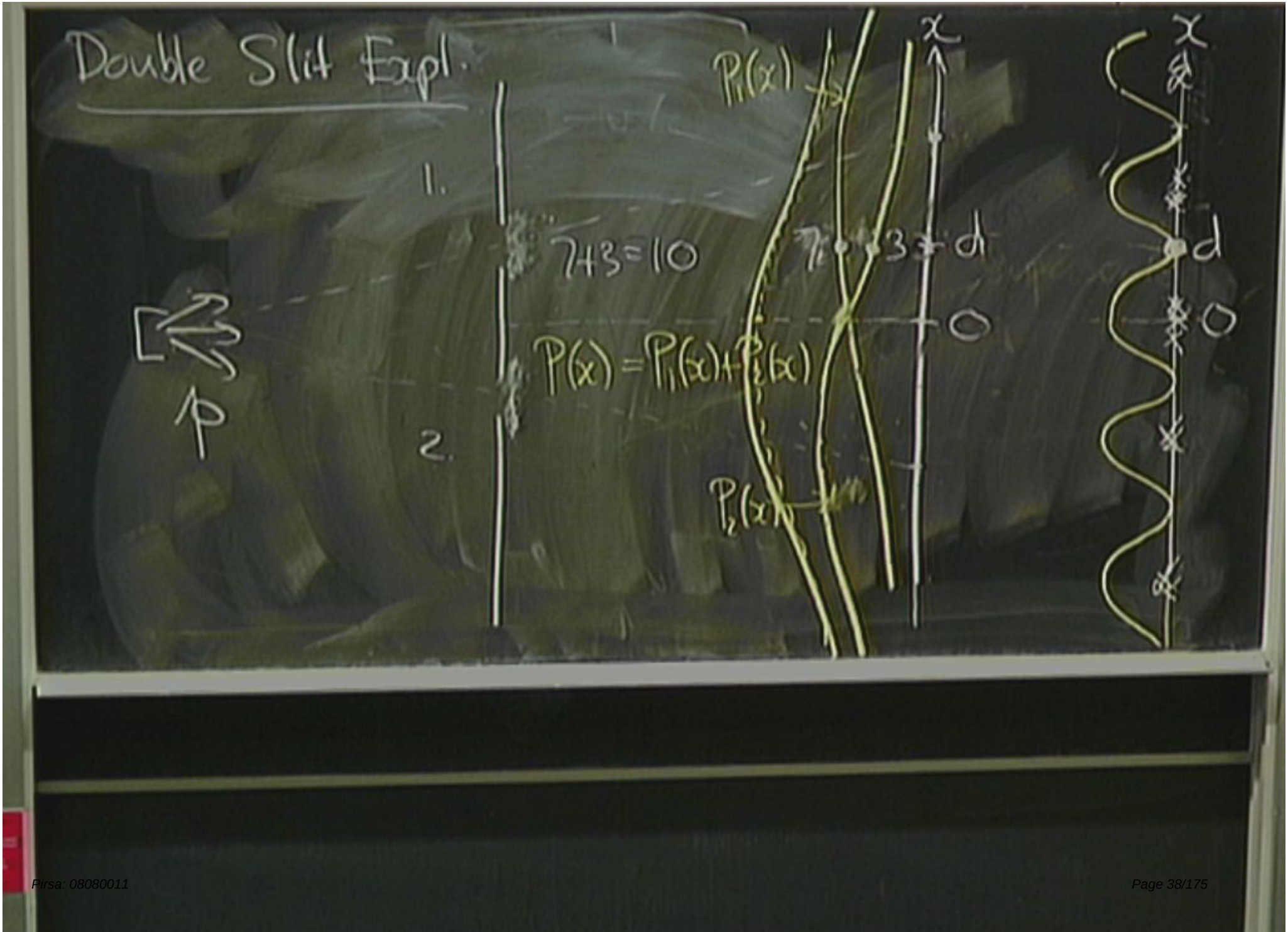

Double Slit Expl.
1.
2.
P
$P_1(x)$
$P_2(x)$
$P(x) = P_1(x) + P_2(x)$
x
$r_2 - r_1 = d$
0

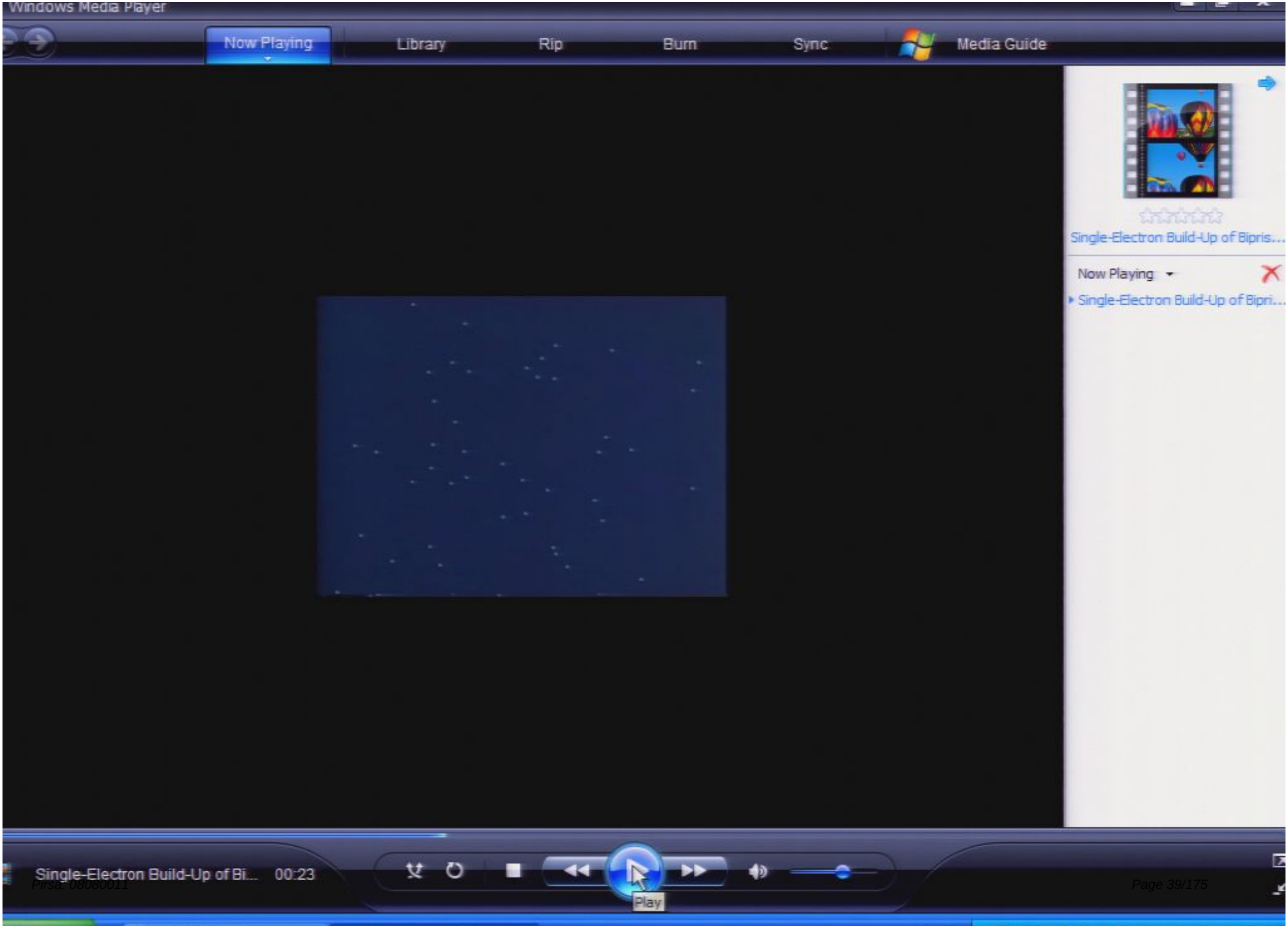

Double Slit Expl.
1.
2.
P
$P_1(x)$
$P_2(x)$
$P(x) = P_1(x) + P_2(x)$
x
x
d
0
d
0

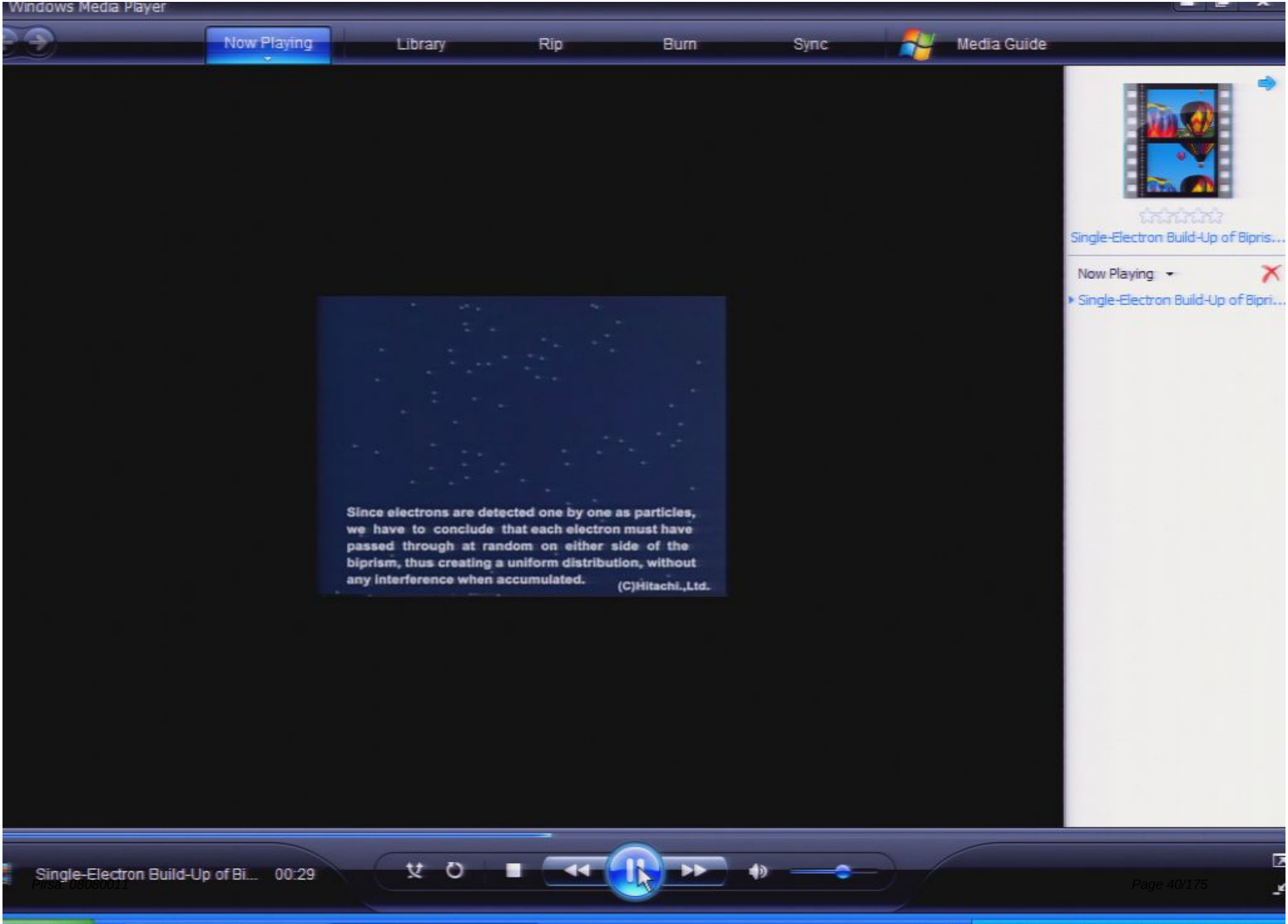

Double Slit Expl.
1.
2.
7+3=10
P(x)=P1(x)+P2(x)
P1(x)
P2(x)
x
x
7+3=d
d
0
d
0

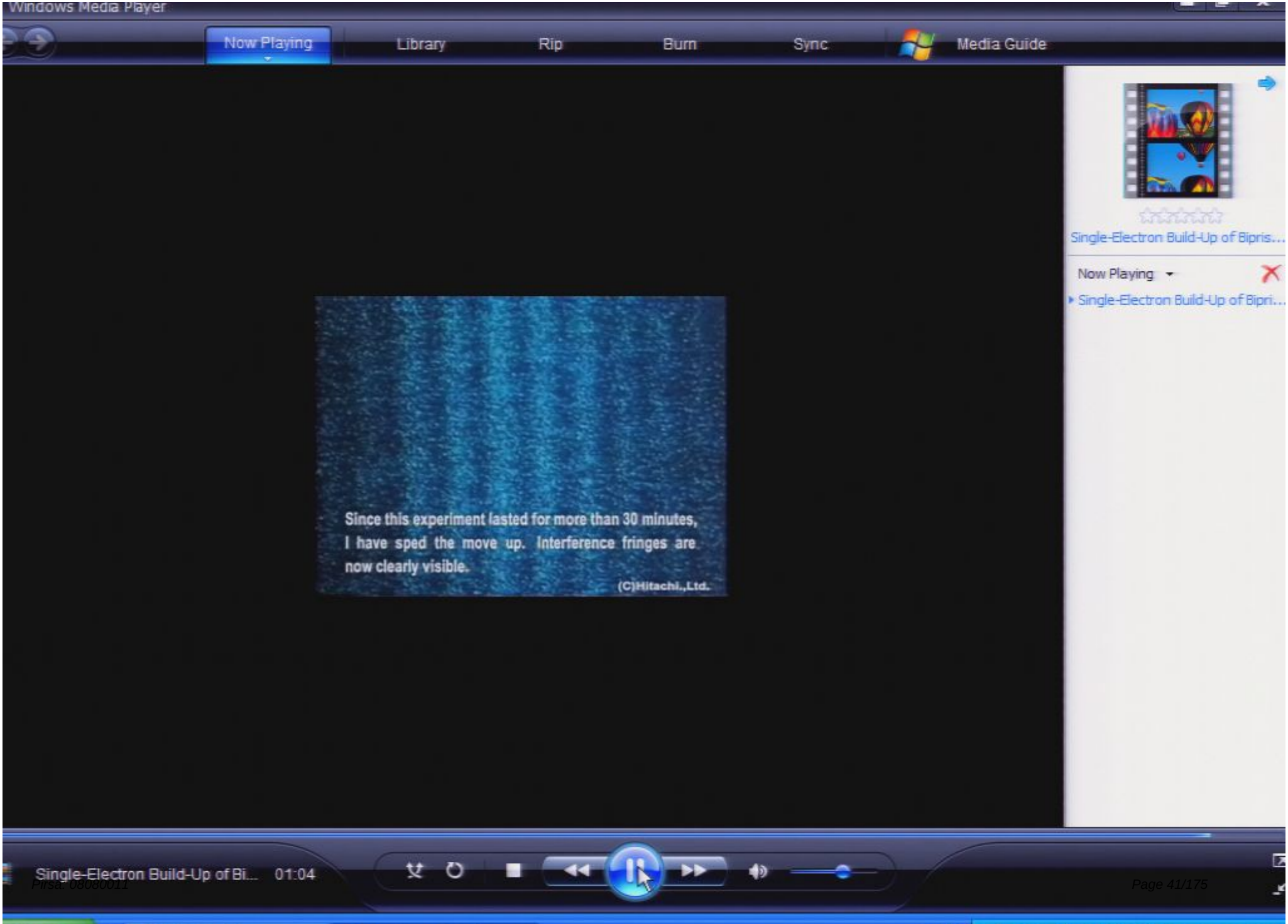

Double Slit Expl.
1.
2.
P
$P_1(x)$
$P_2(x)$
7+3=10
7+3=d
0
$P(x) = P_1(x) + P_2(x)$
x
x
d
0


Double Slit Expl.
1.
2.
7+3=10
P(x)=P1(x)+P2(x)
P1(x)
P2(x)
x
d
0

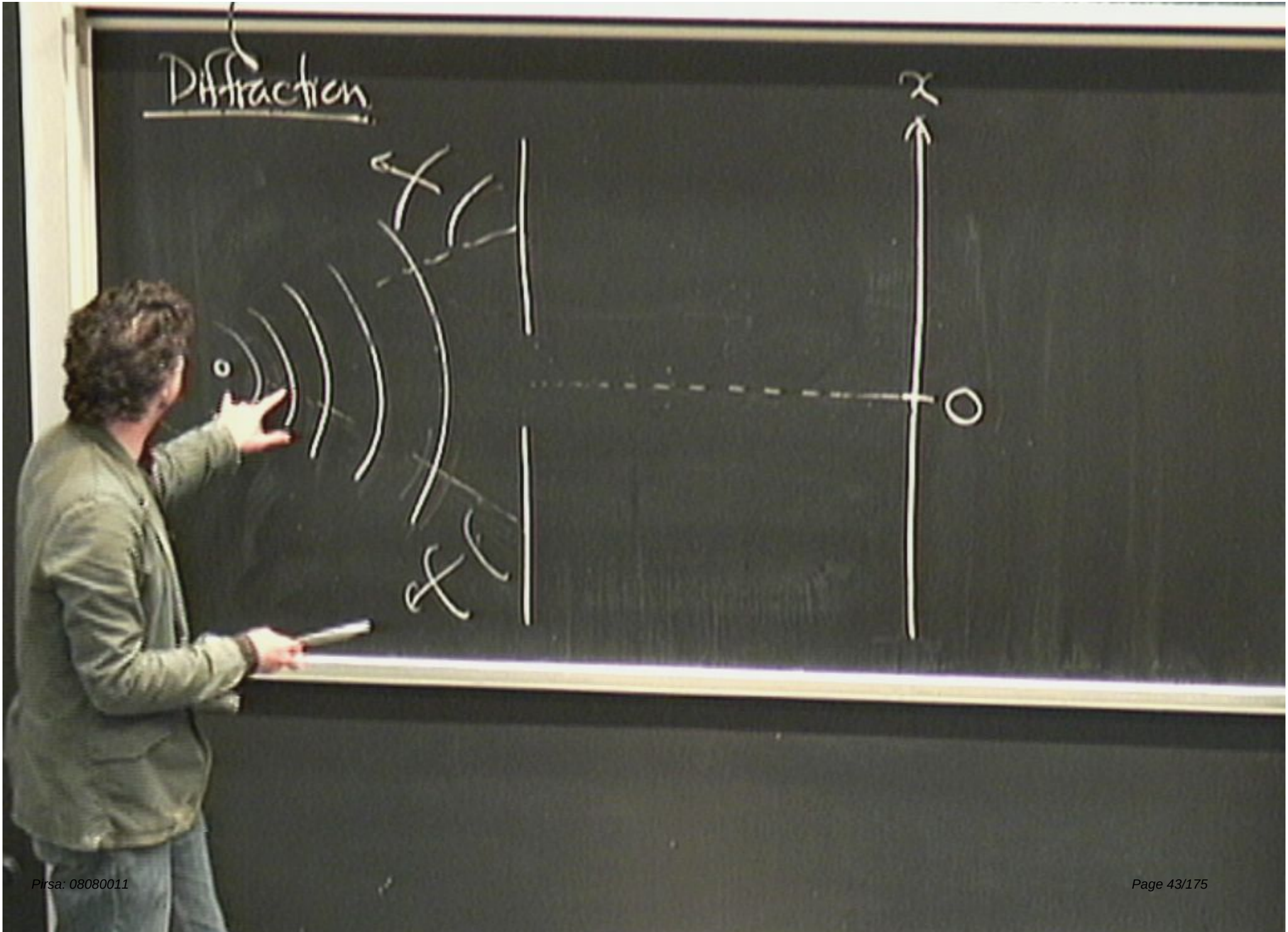

Double Slit Expl.
1.
2.
P
7+3=10
P(x)=P1(x)+P2(x)
P1(x)
P2(x)
x
d
0

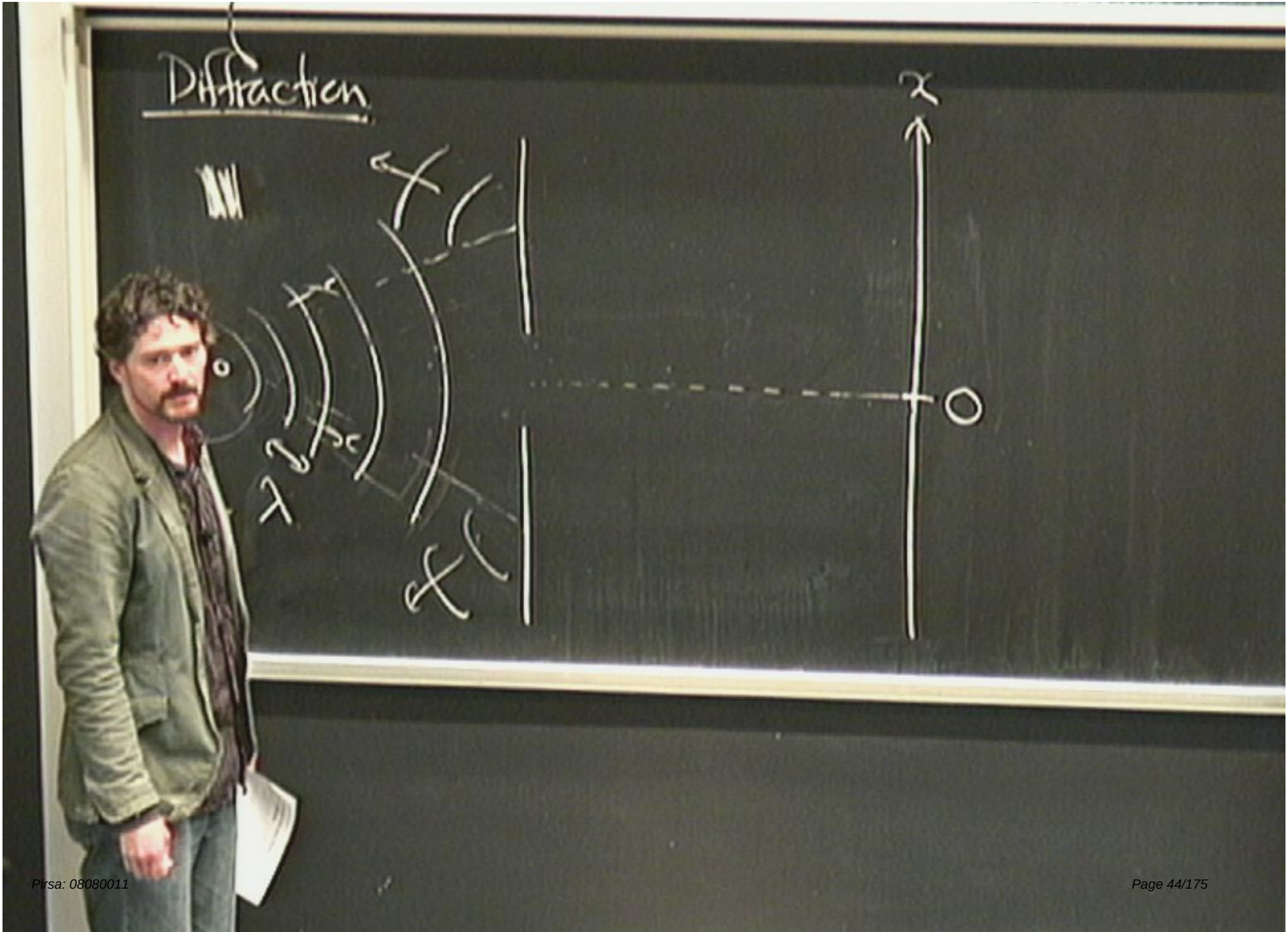

Windows Media Player
Now Playing
Library
Rip
Burn
Sync
Media Guide
Single-Electron Build-Up of Bipris...
Now Playing
Single-Electron Build-Up of Bipri...
Single-Electron Build-Up of Bi...
00:23
Play

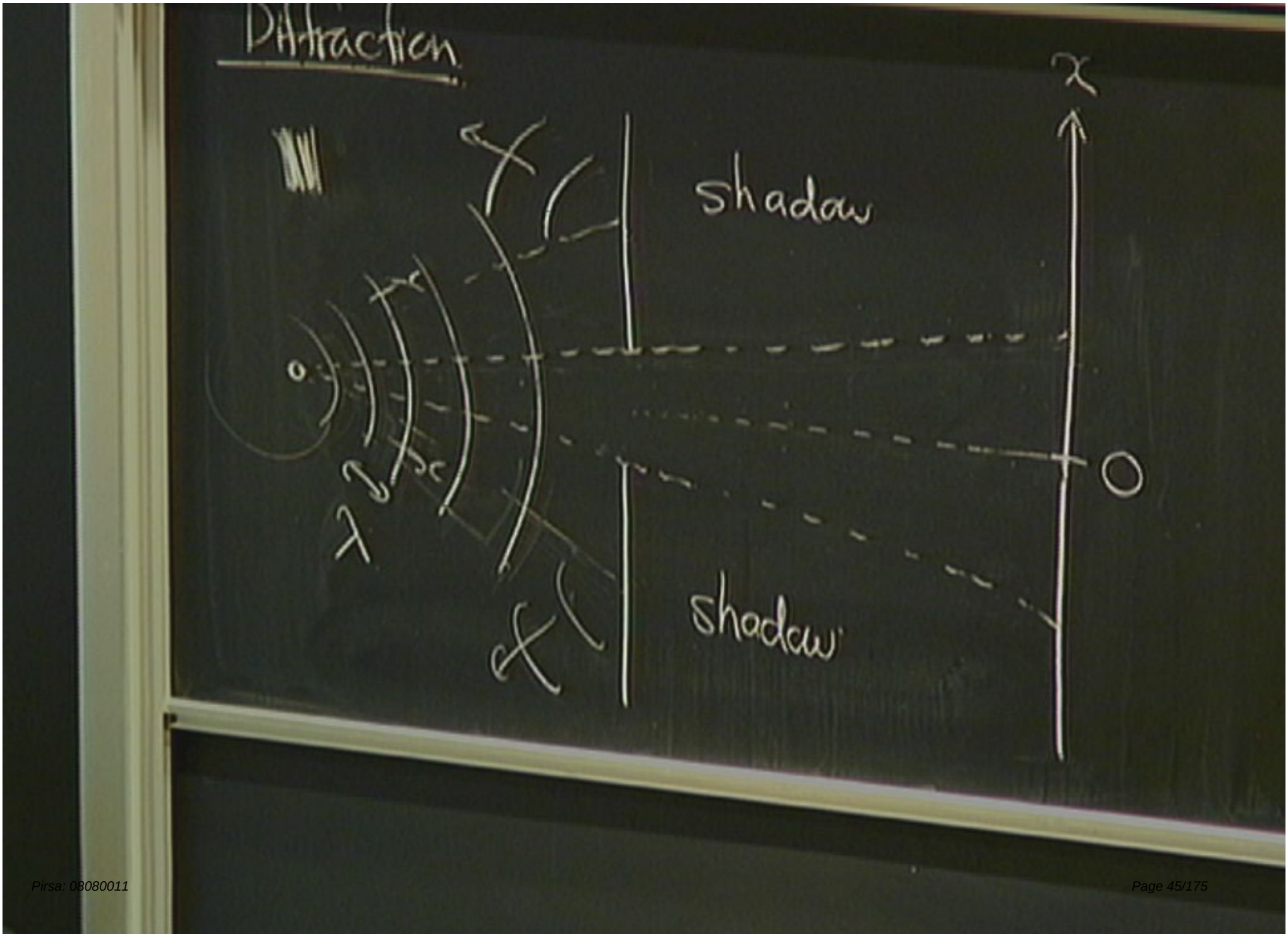

Windows Media Player
Now Playing
Library
Rip
Burn
Sync
Media Guide
Single-Electron Build-Up of Bipris...
Now Playing
Single-Electron Build-Up of Bipri...
Since electrons are detected one by one as particles, we have to conclude that each electron must have passed through at random on either side of the biprism, thus creating a uniform distribution, without any interference when accumulated.
(C)Hitachi.,Ltd.
Single-Electron Build-Up of Bi... 00:29

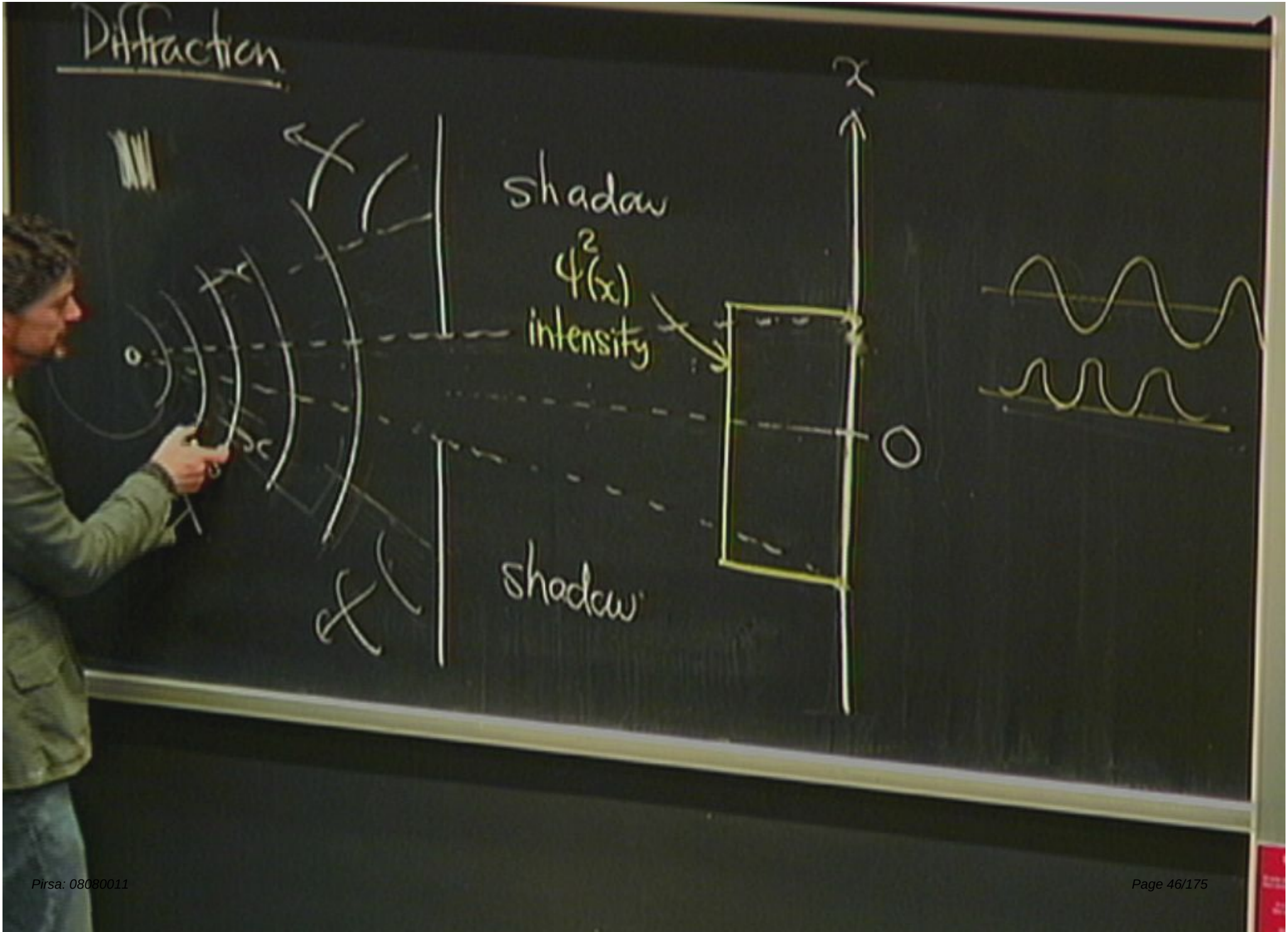

Windows Media Player
Now Playing
Library
Rip
Burn
Sync
Media Guide
Single-Electron Build-Up of Bipris...
Now Playing
Single-Electron Build-Up of Bipri...
Since this experiment lasted for more than 30 minutes,
I have sped the move up. Interference fringes are
now clearly visible.
(C)Hitachi.,Ltd.
Single-Electron Build-Up of Bi... 01:04

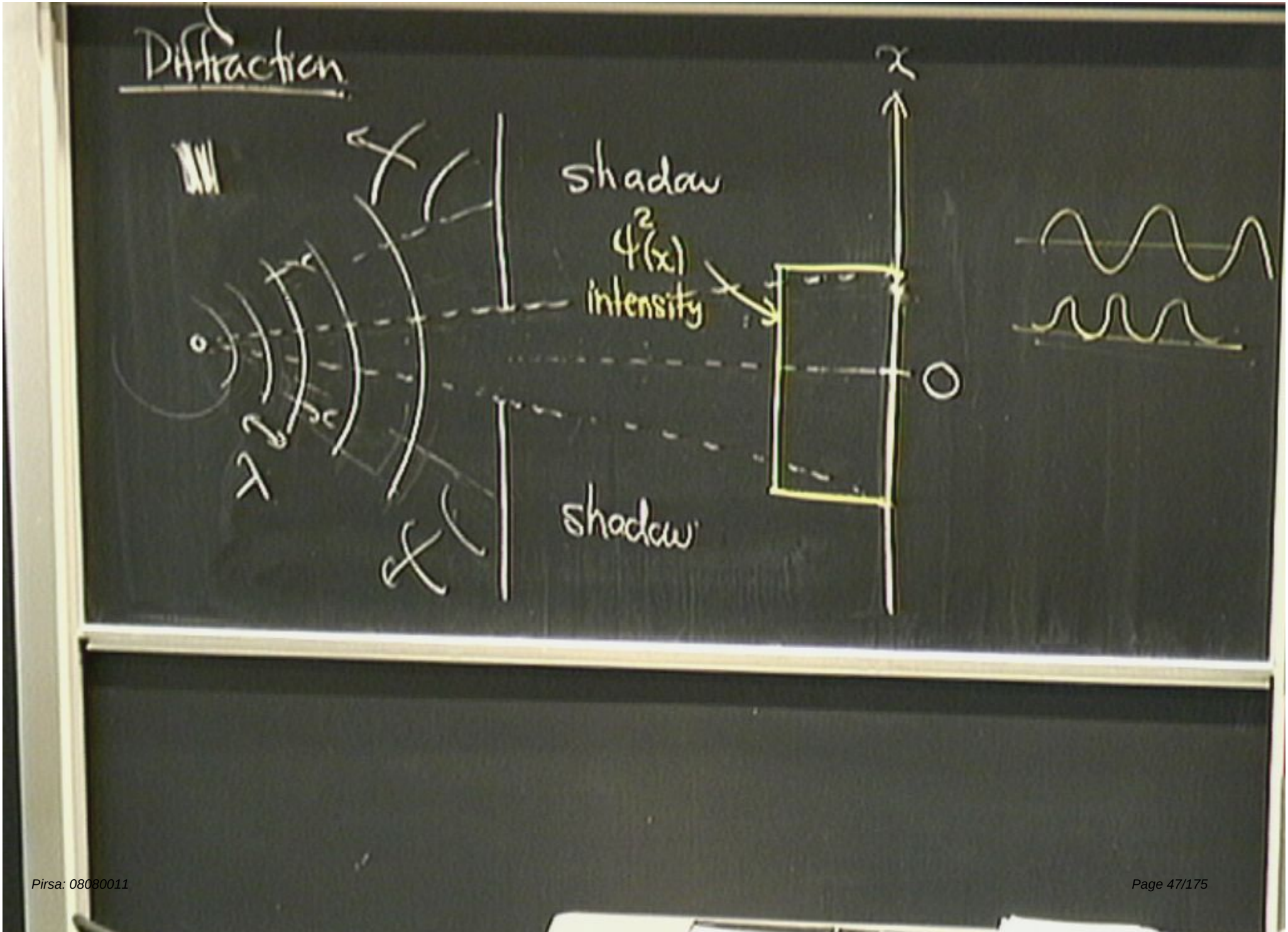

Windows Media Player
Now Playing
Library
Rip
Burn
Sync
Media Guide
1 item
1 minute
Now Playing
Single-Electron Build-Up of Bipri...

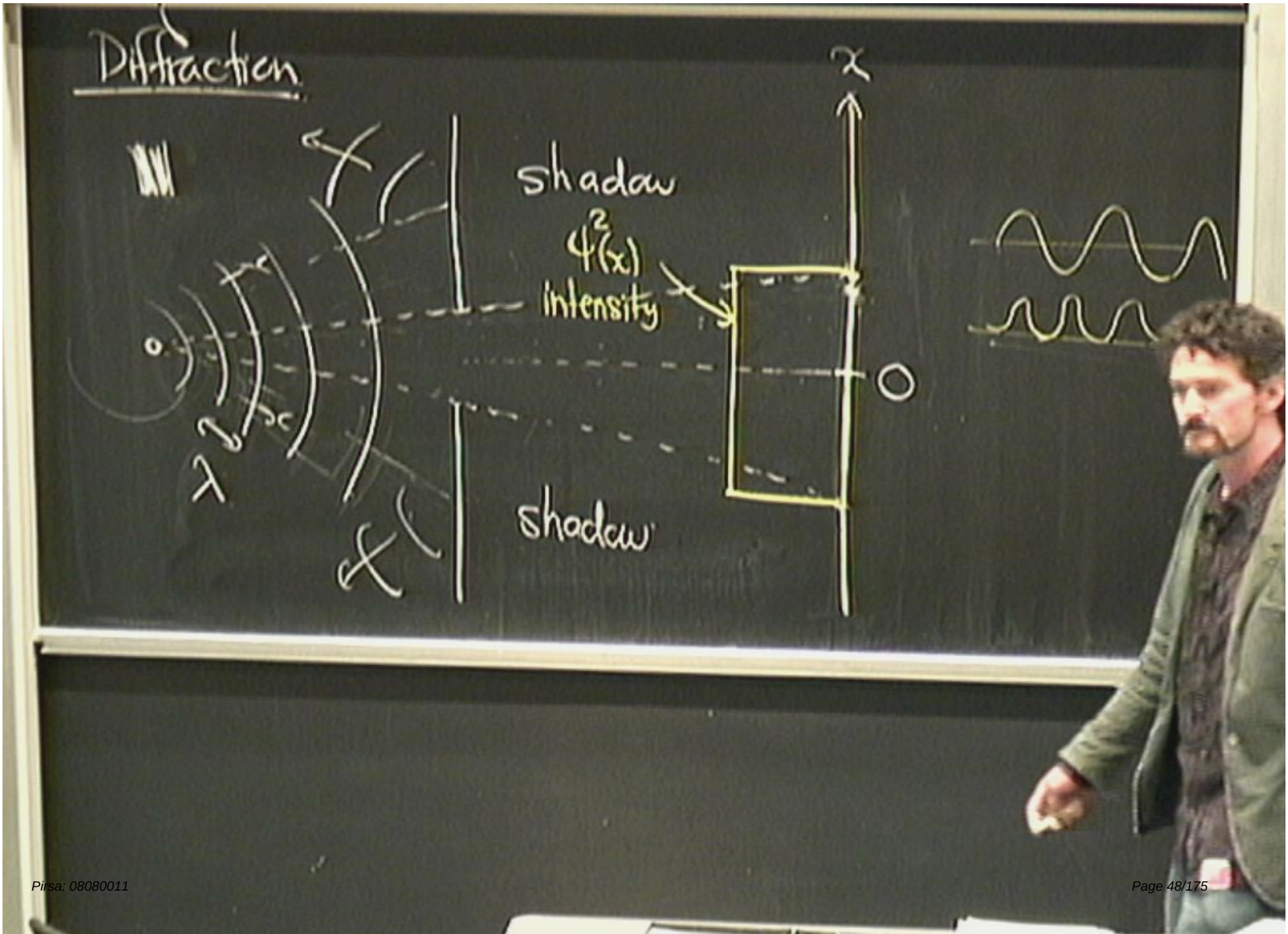

Diffraction
x
O

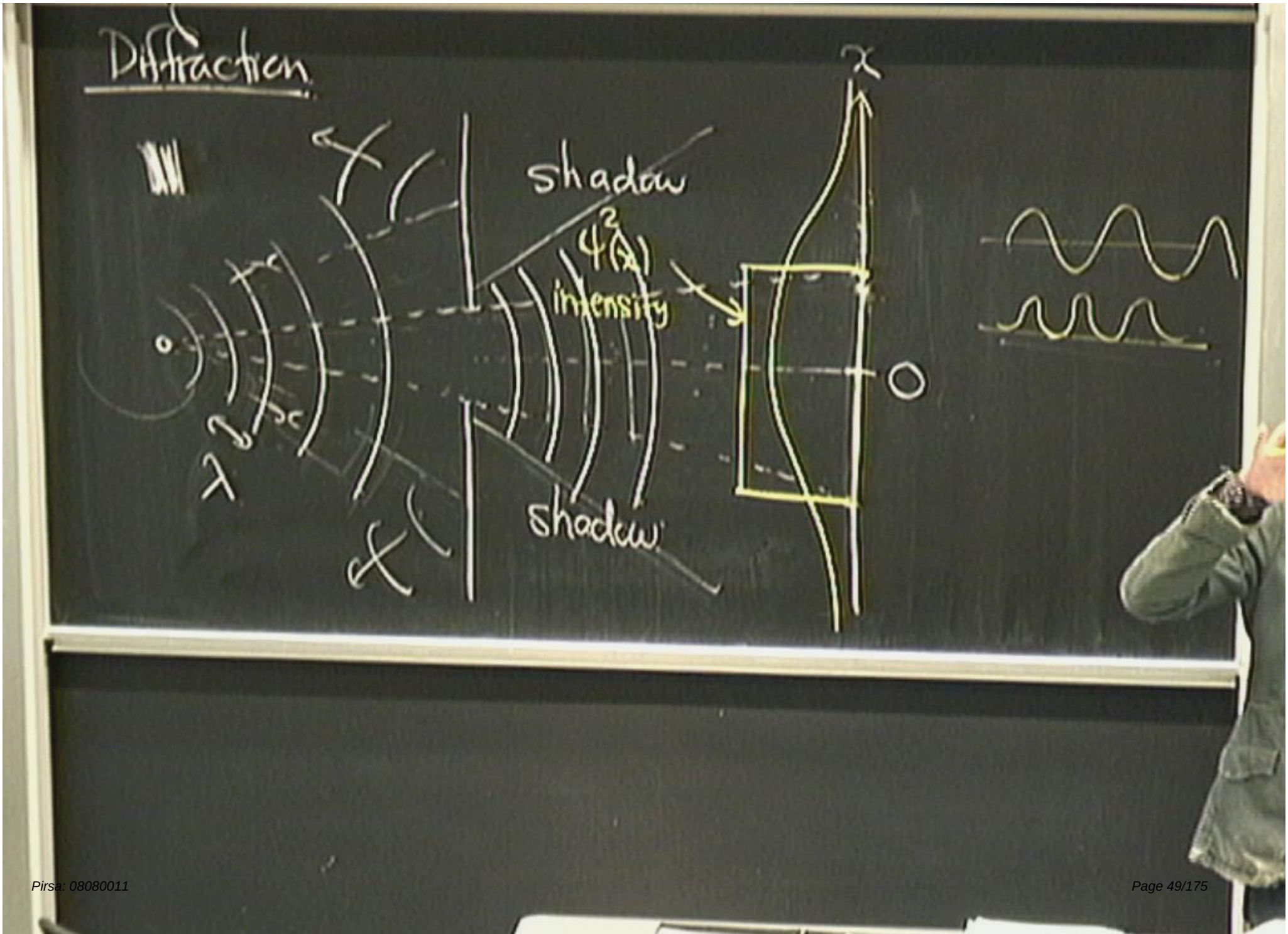

Diffraction
x
O
λ

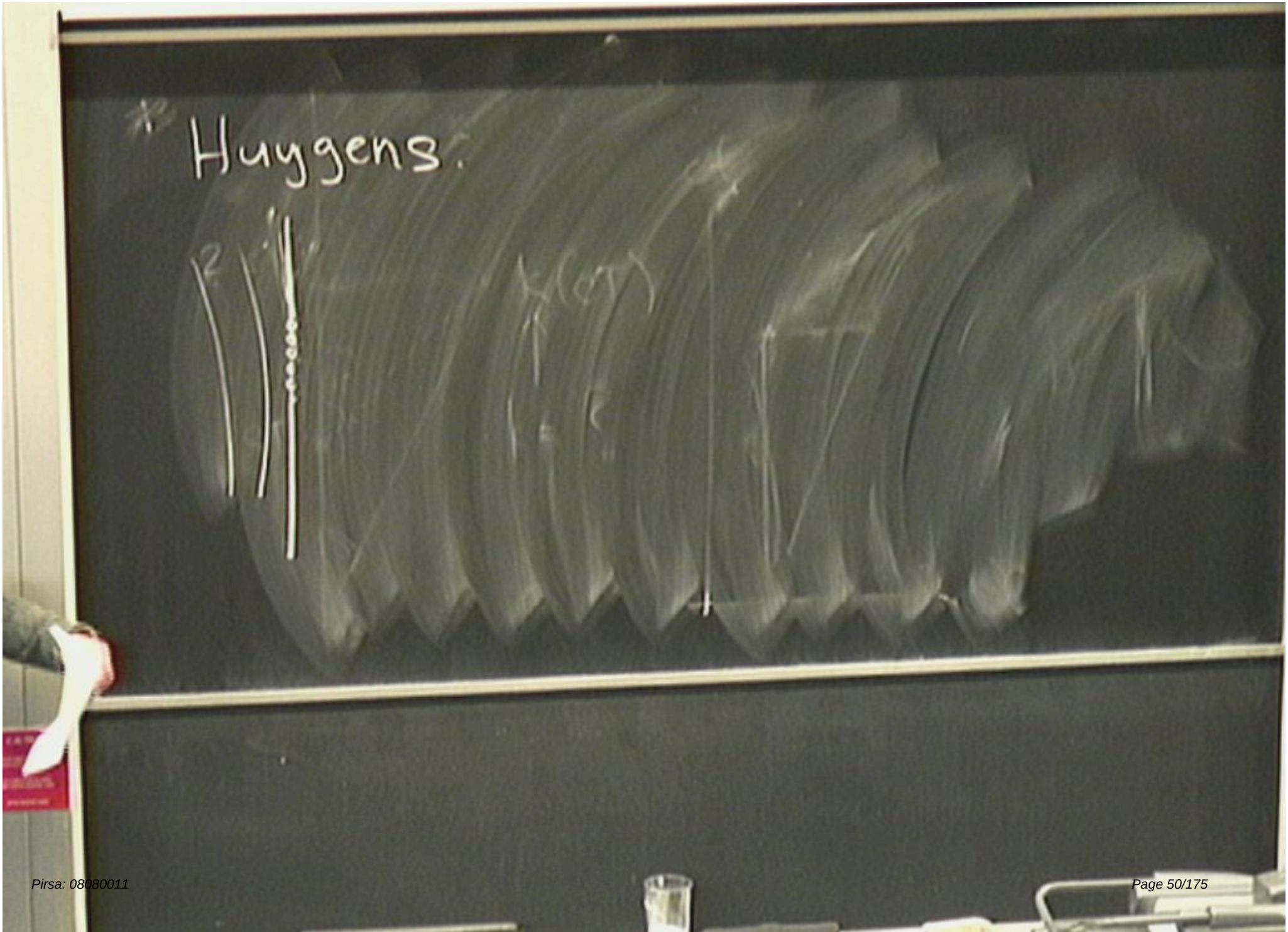

Diffraction
x
shadow
O
λ
shadow

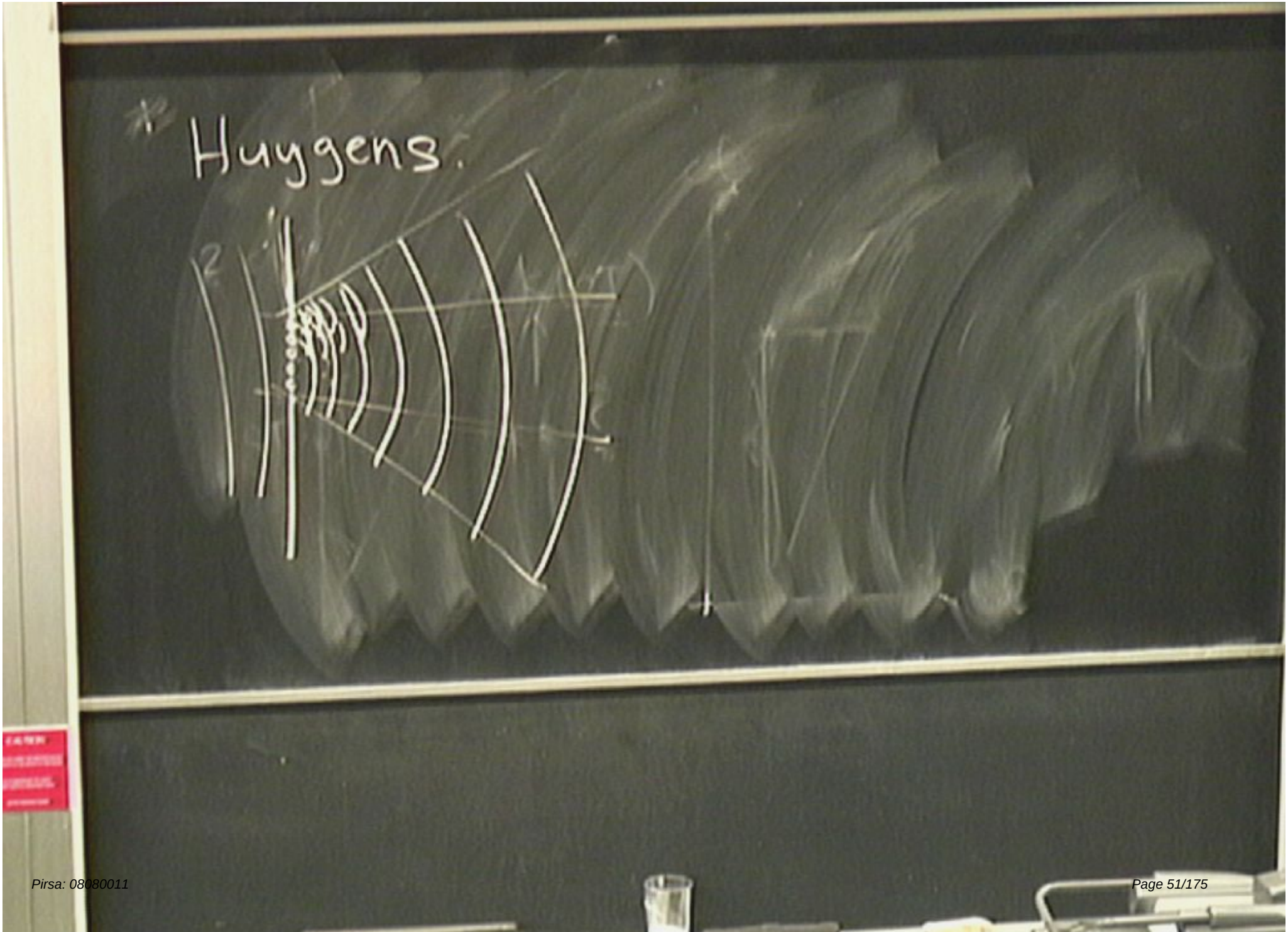

Diffraction
shadow
$\psi^2(x)$
intensity
x
0
shadow

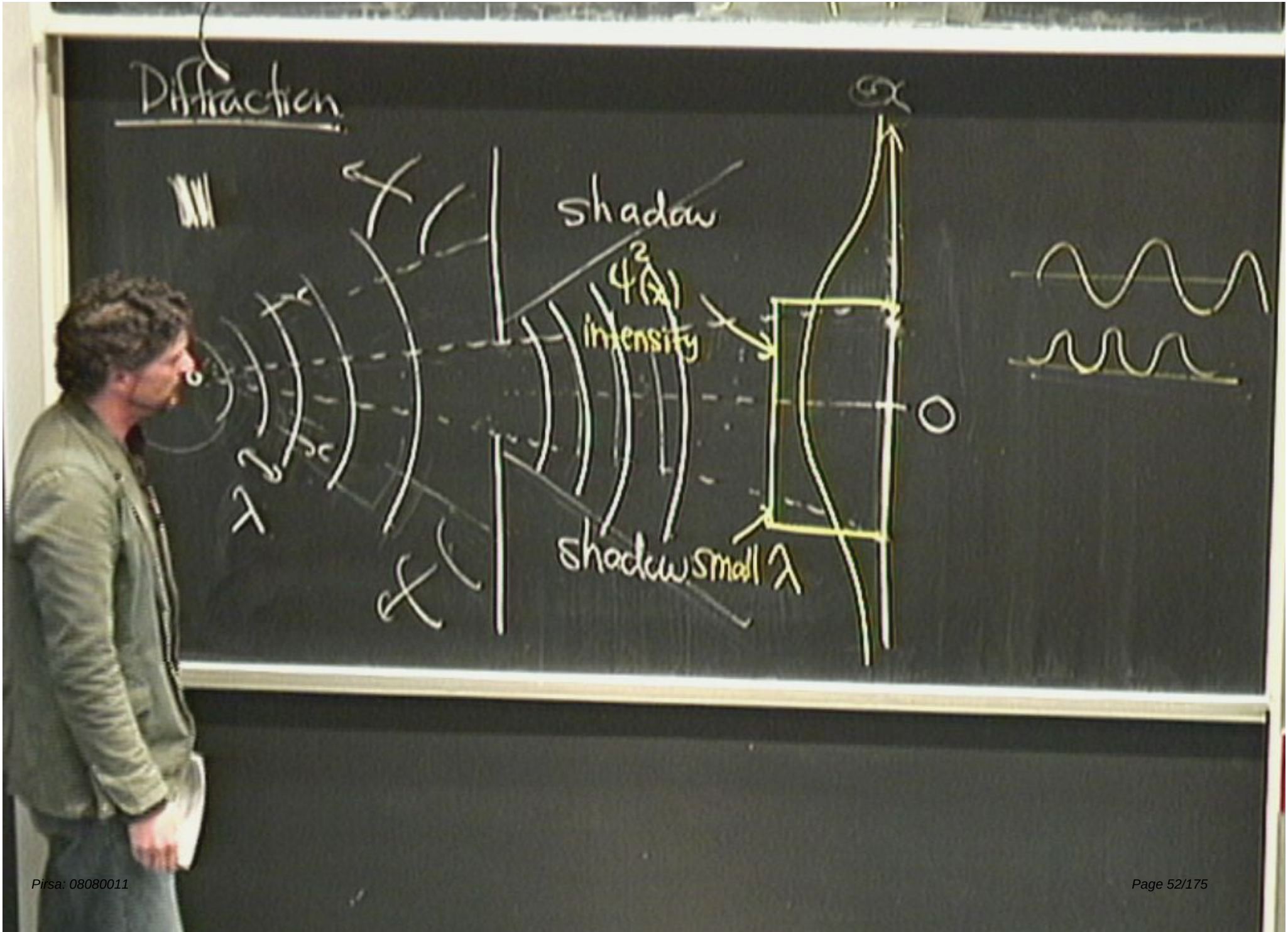

Diffraction
shadow
$\psi^2(x)$
intensity
shadow
x
0
λ

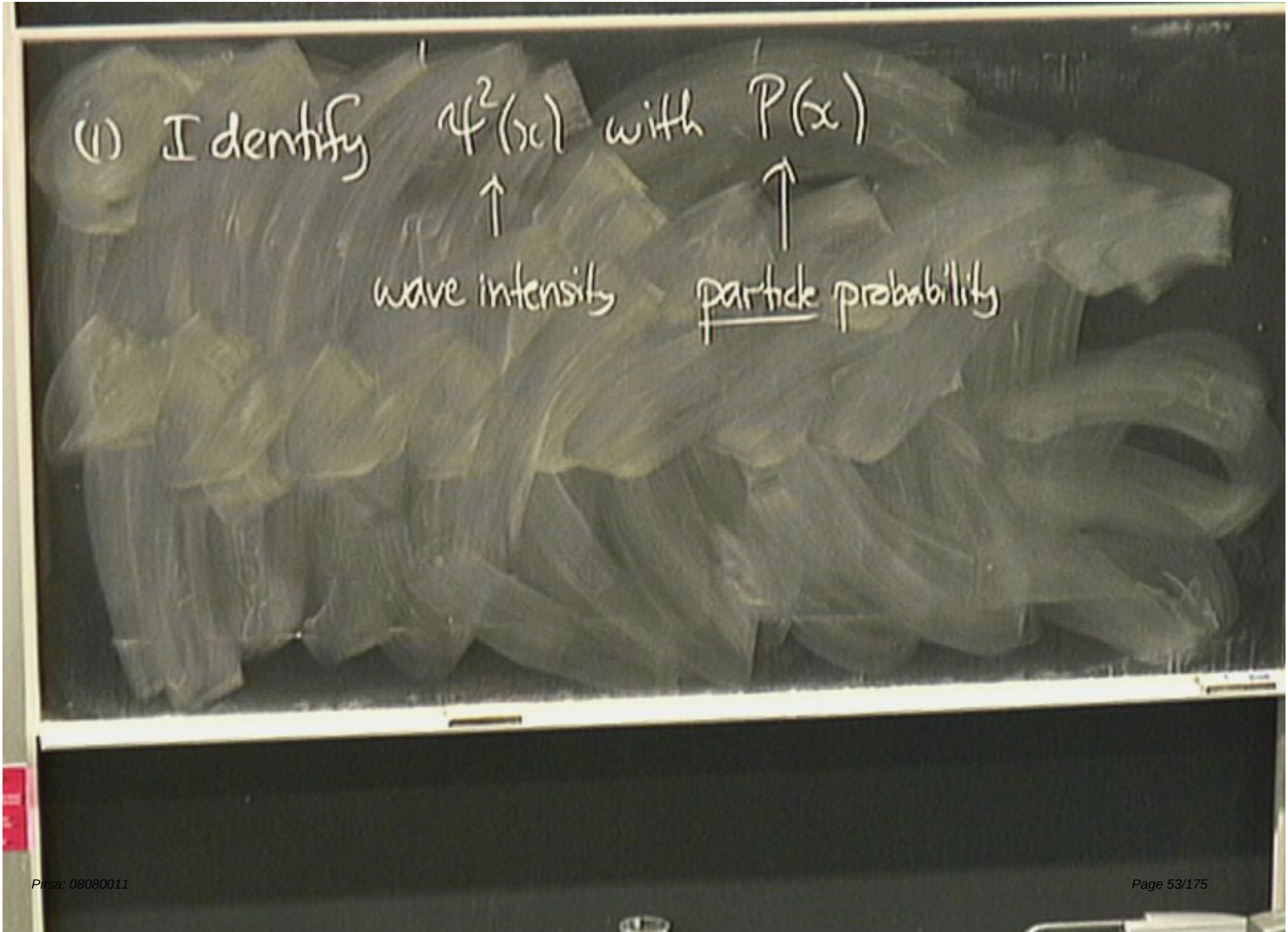

Diffraction
shadow
$\psi^2(x)$
intensity
x
0
λ
shadow


Diffraction
shadow
$\psi^2(x)$
intensity
shadow
x
O
λ


Huygens.


Huygens.


Diffraction
shadow
intensity
shadow small λ


(1) Identify $\psi^2(x)$ with $P(x)$
wave intensity
particle probability

(1) Identify $\psi^2(x)$ with $P(x)$

↑ wave intensity ↑ particle probability

(2) small $\lambda \leftrightarrow$ large p

(1) Identify $\psi^2(x)$ with $P(x)$

↑ wave intensity ↑ particle probability

(2) small λ ↔ large p

large λ ↔ small p

(1) Identify $\psi^2(x)$ with $P(x)$

↑ wave intensity ↑ particle probability

(2) small λ ⟷ large p

large λ ⟷ small p

Guess: $\lambda \propto \frac{1}{p}$

(1) Identify $\psi^2(x)$ with $P(x)$

$\psi^2(x)$: wave intensity

$P(x)$: particle probability

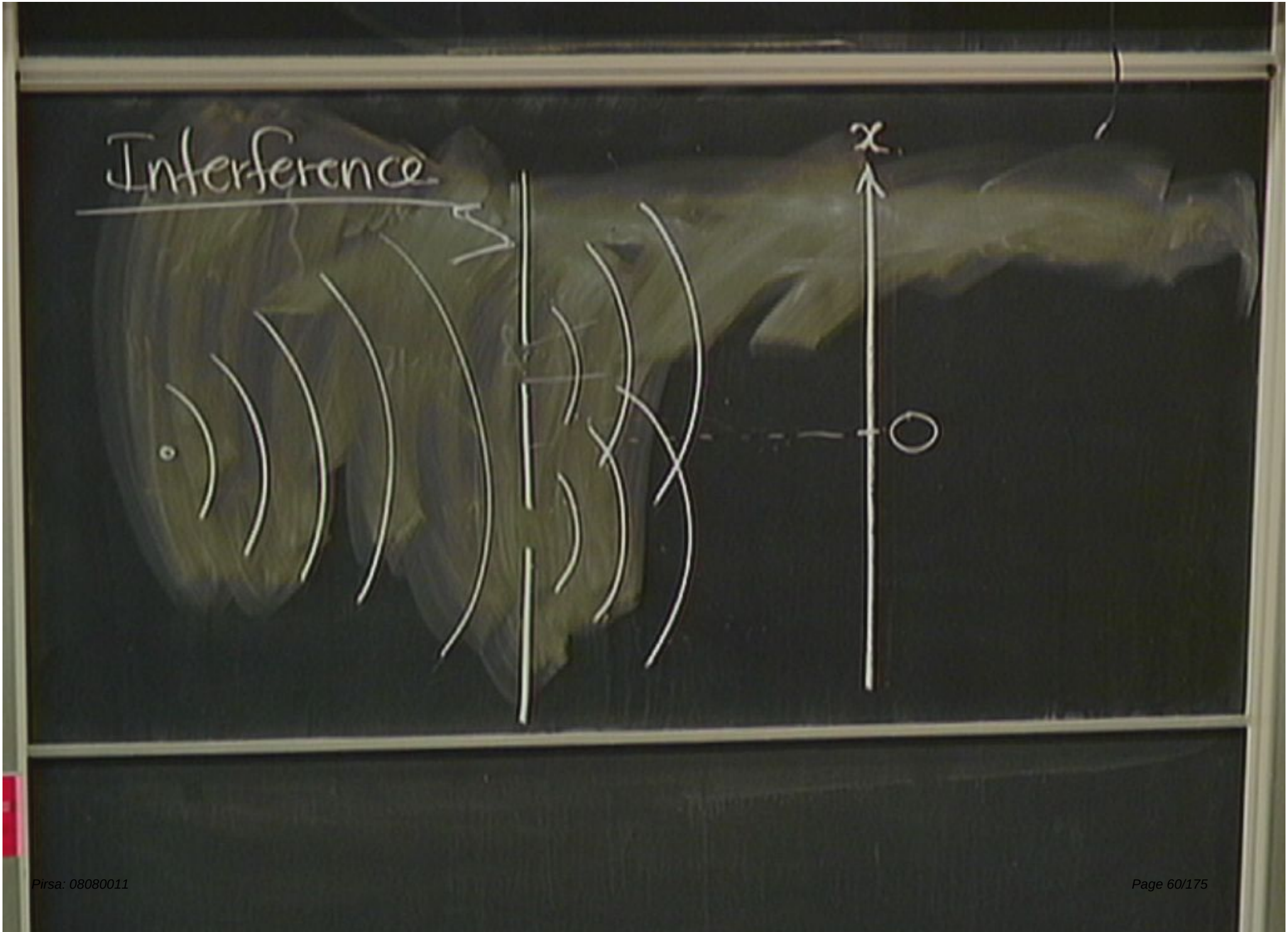
(2) small λ $\leftrightarrow$ large p

large λ $\leftrightarrow$ small p

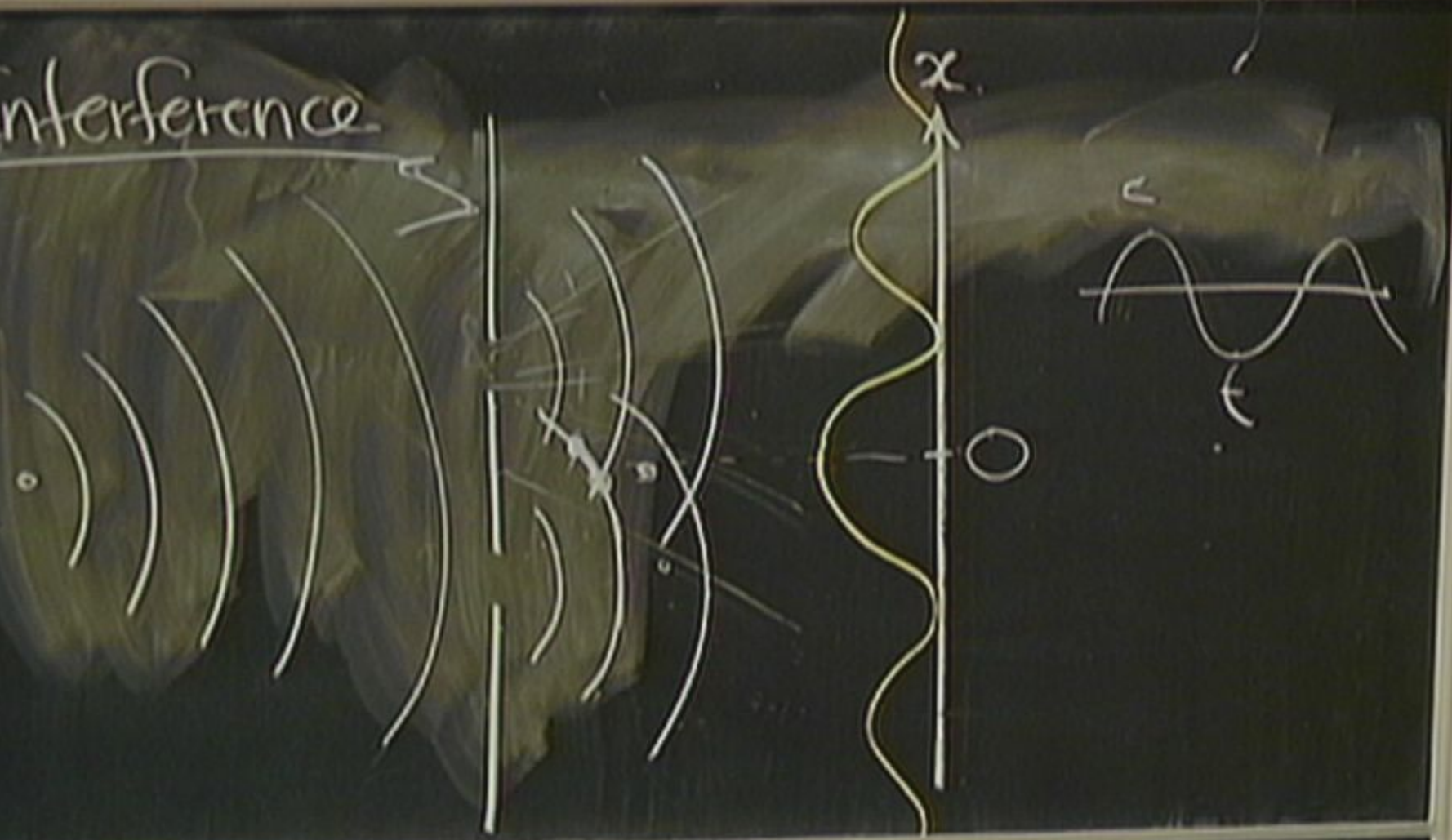
Guess: $\lambda \propto \frac{1}{p}$

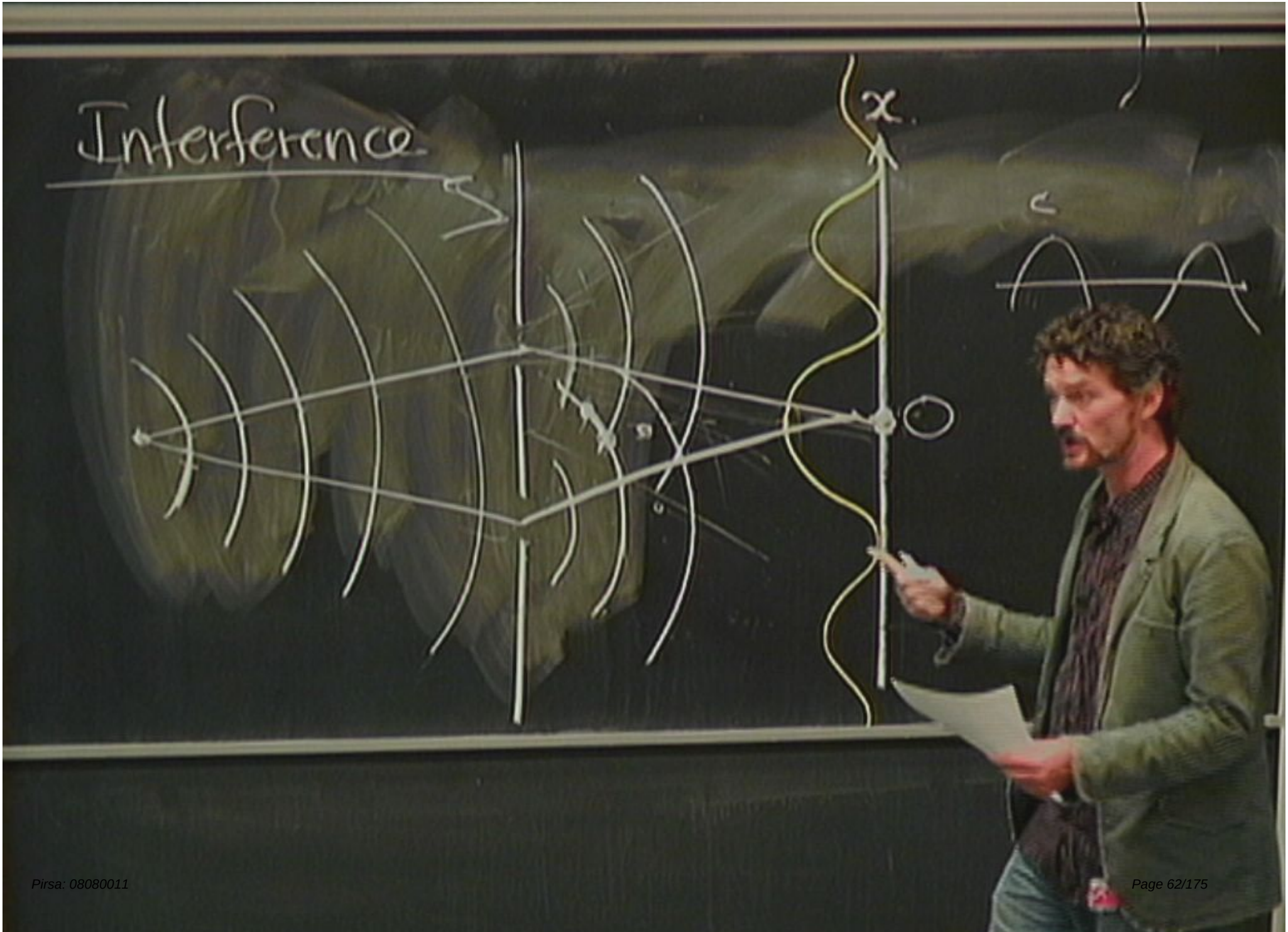
Interference

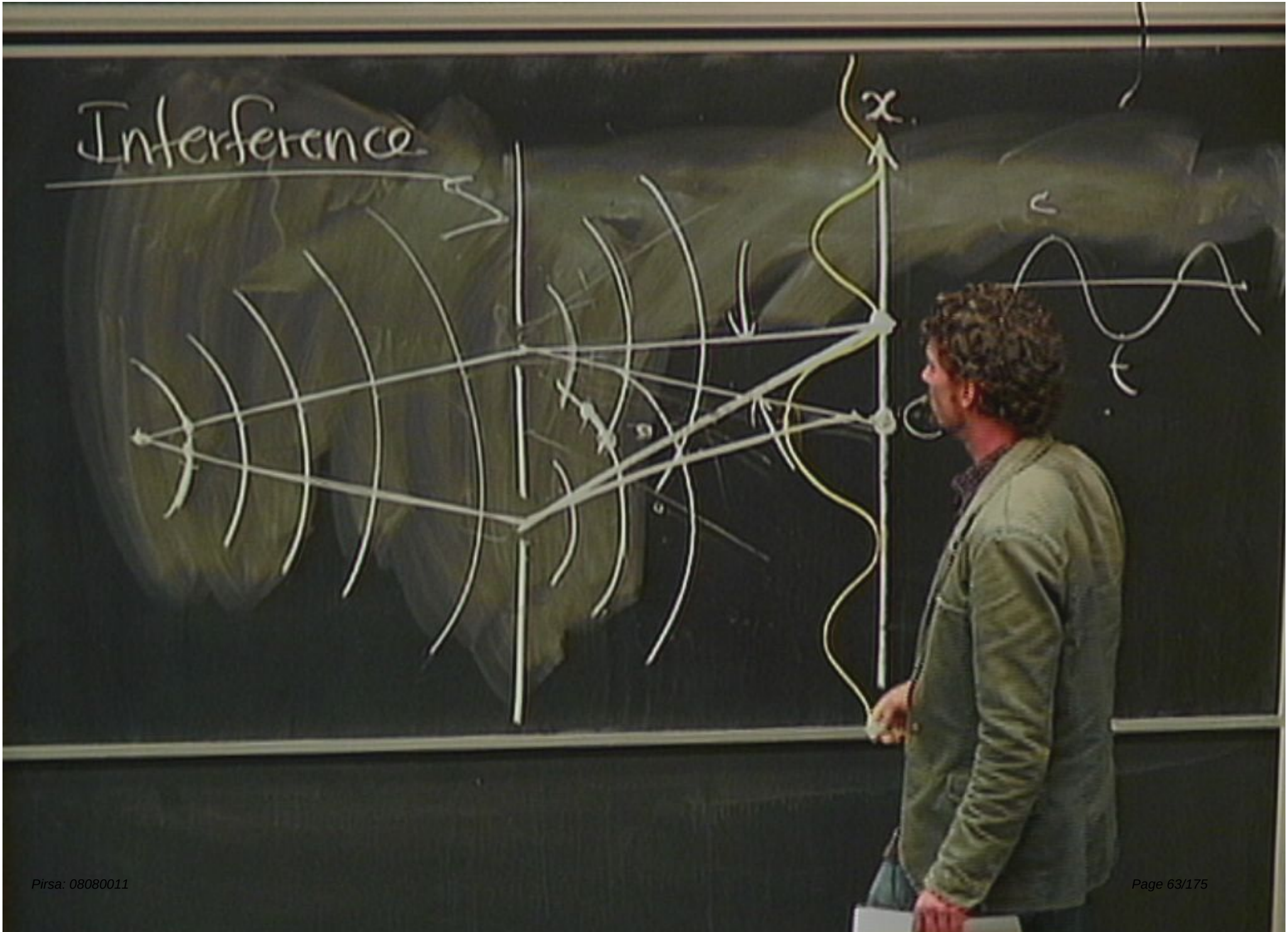
Interference

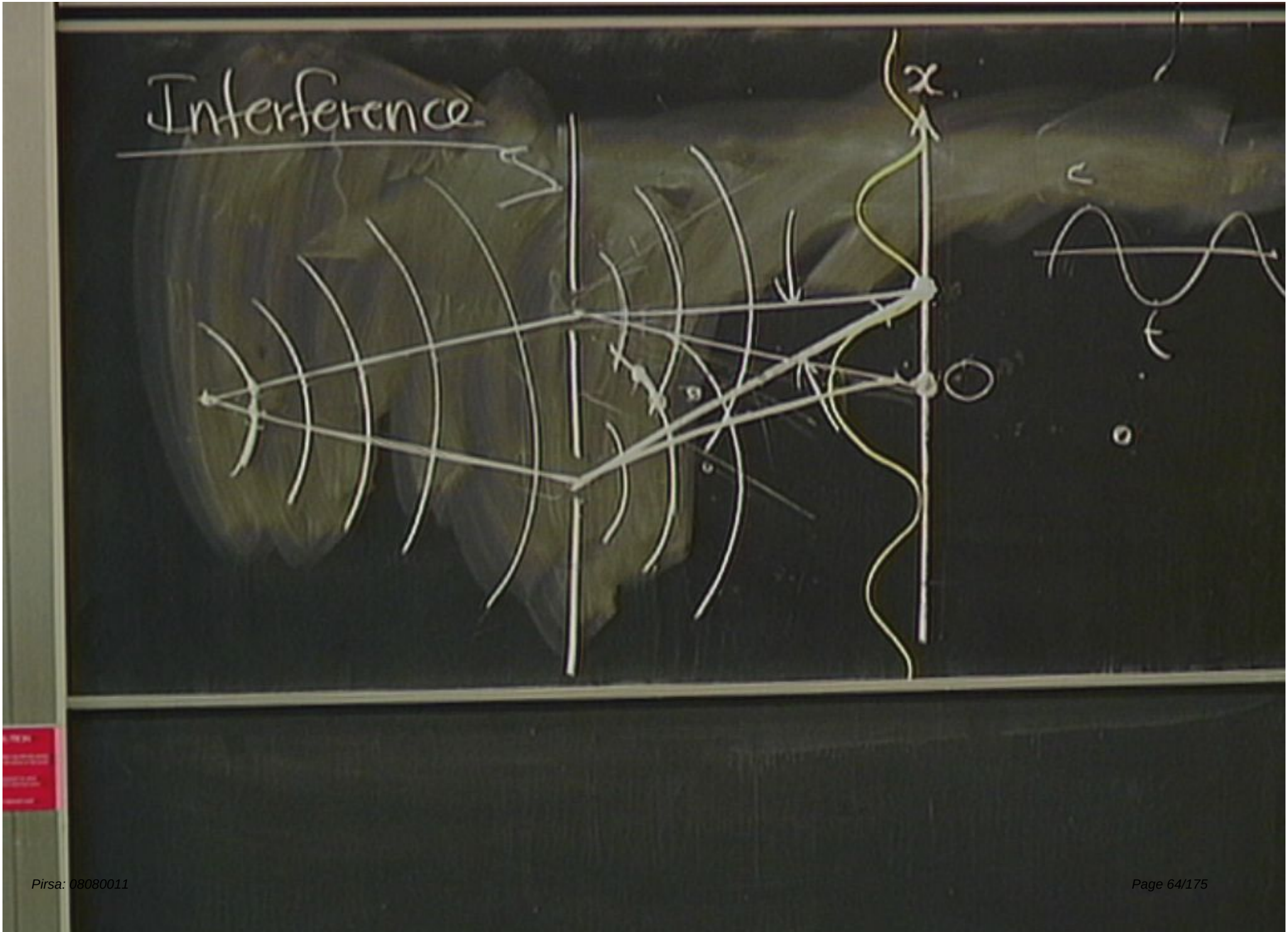

Interference
x
O

Interference




Interference
x
O


Interference
x


Interference
x
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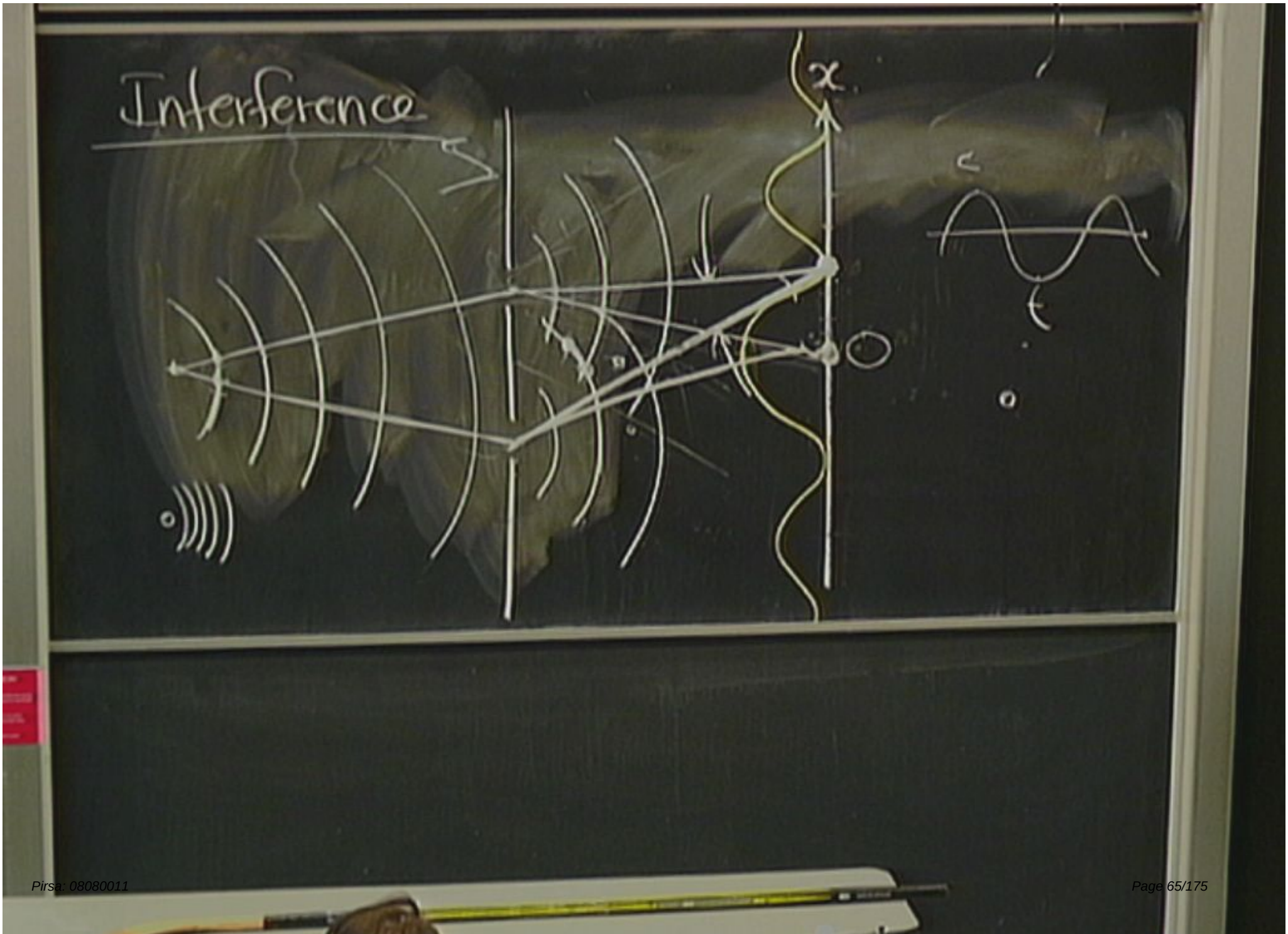
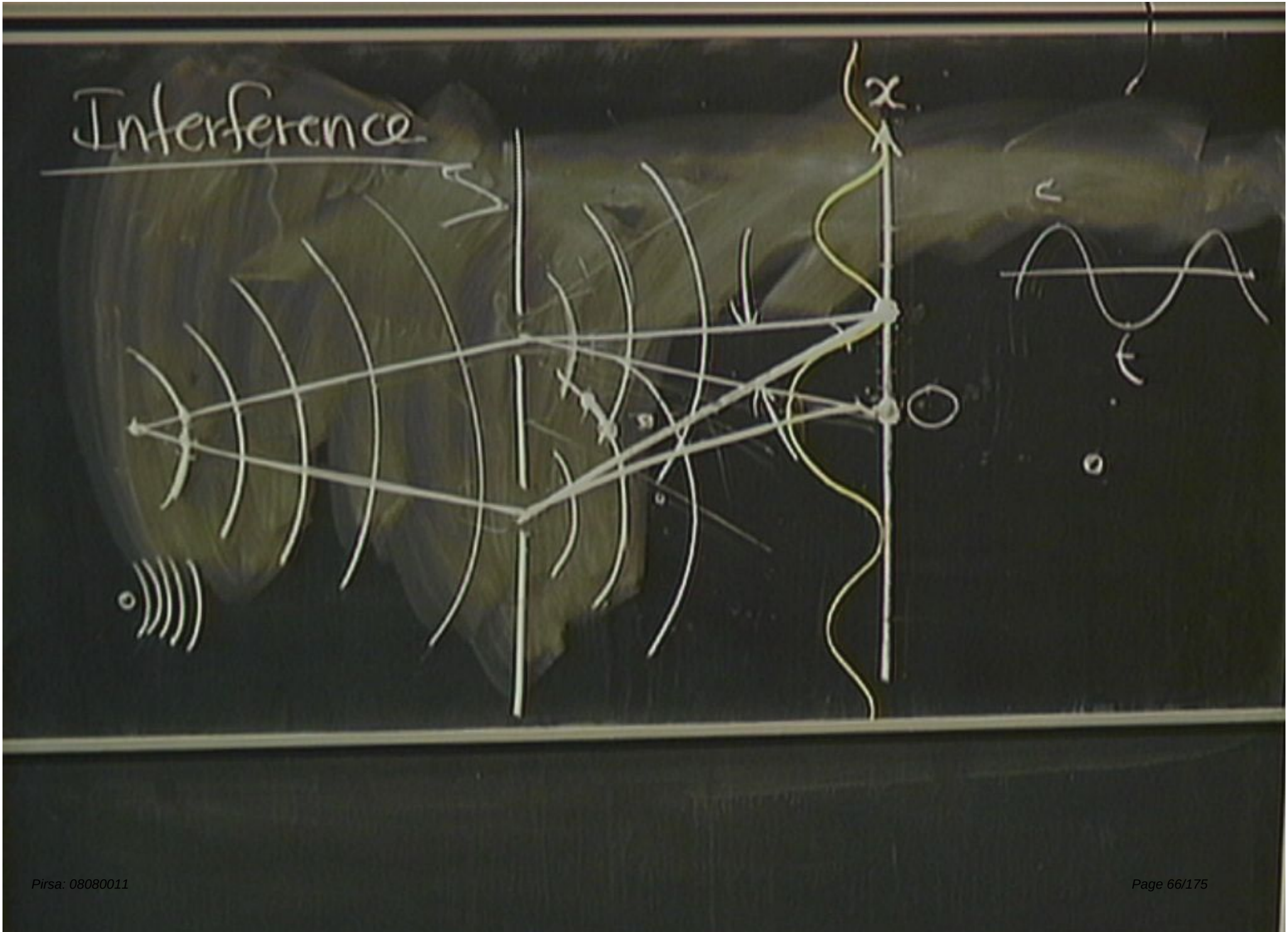
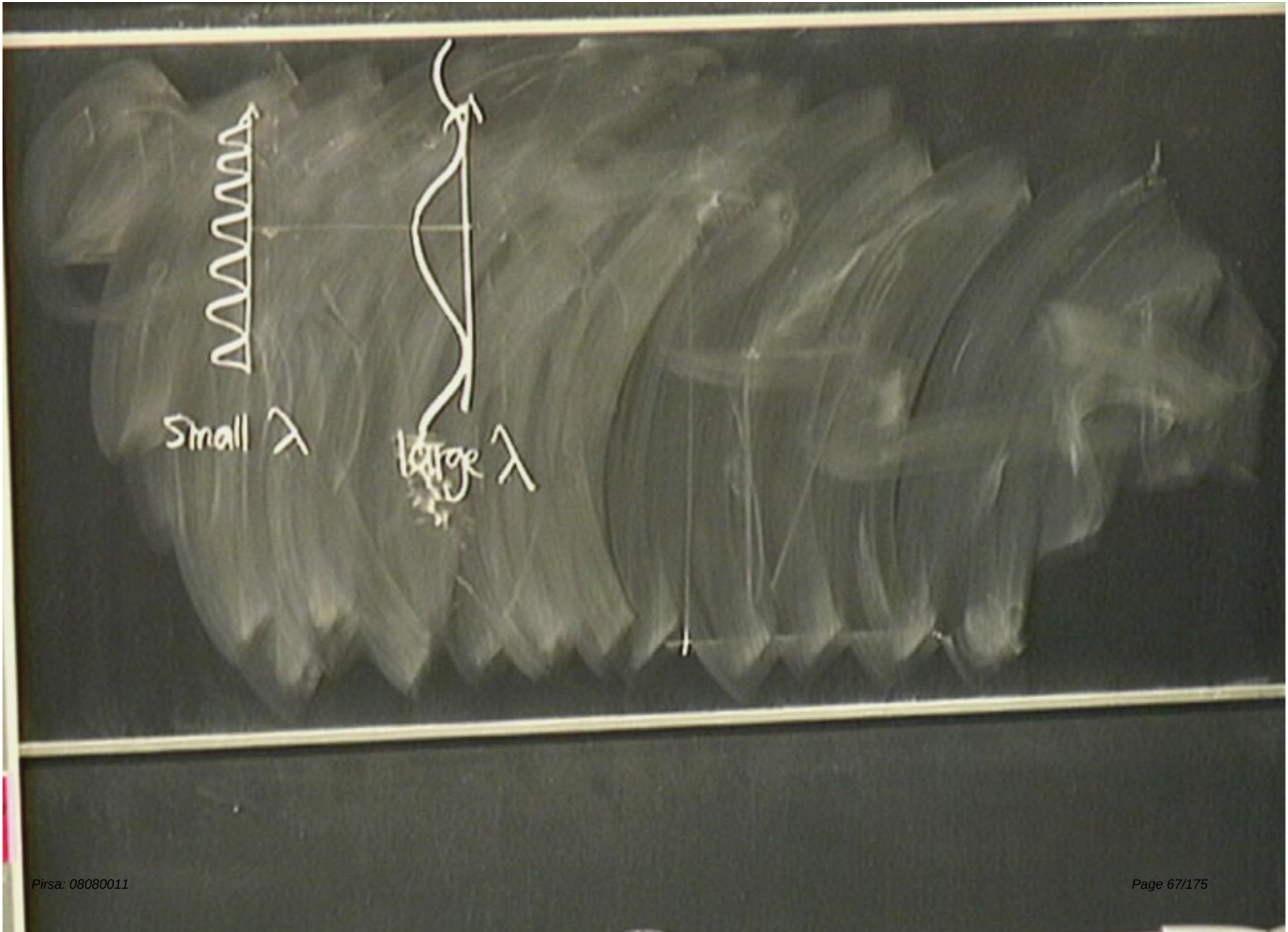
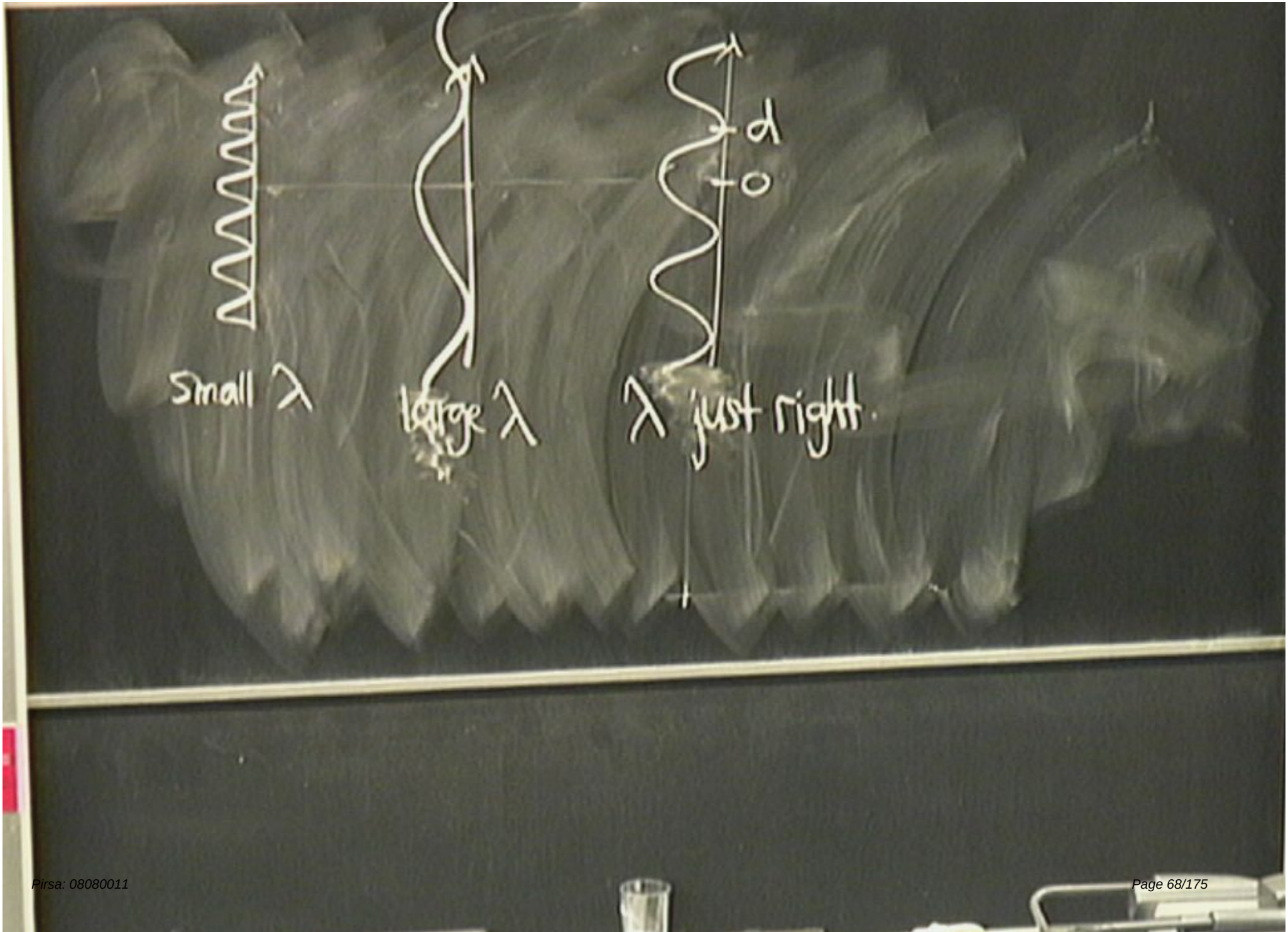
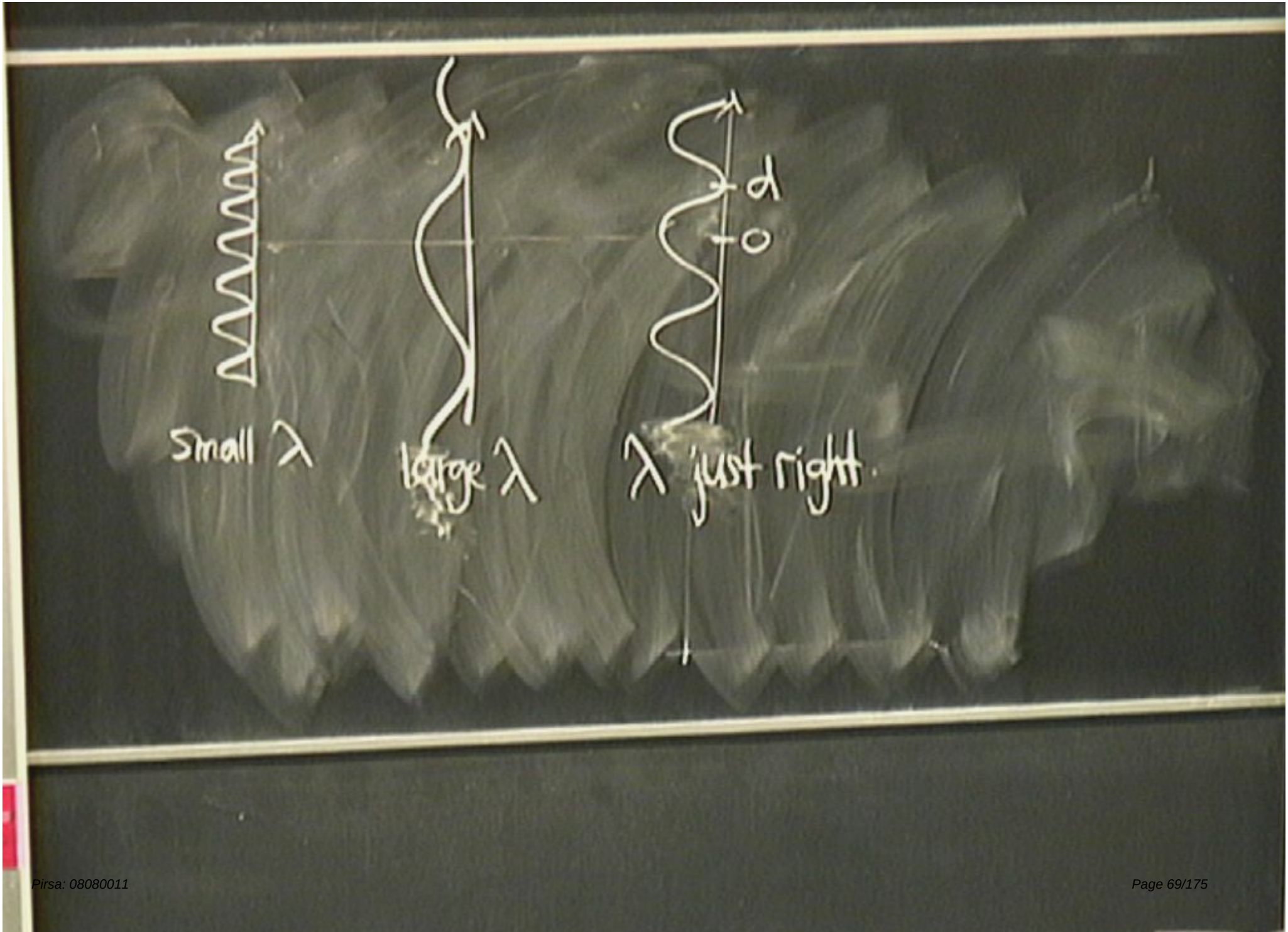
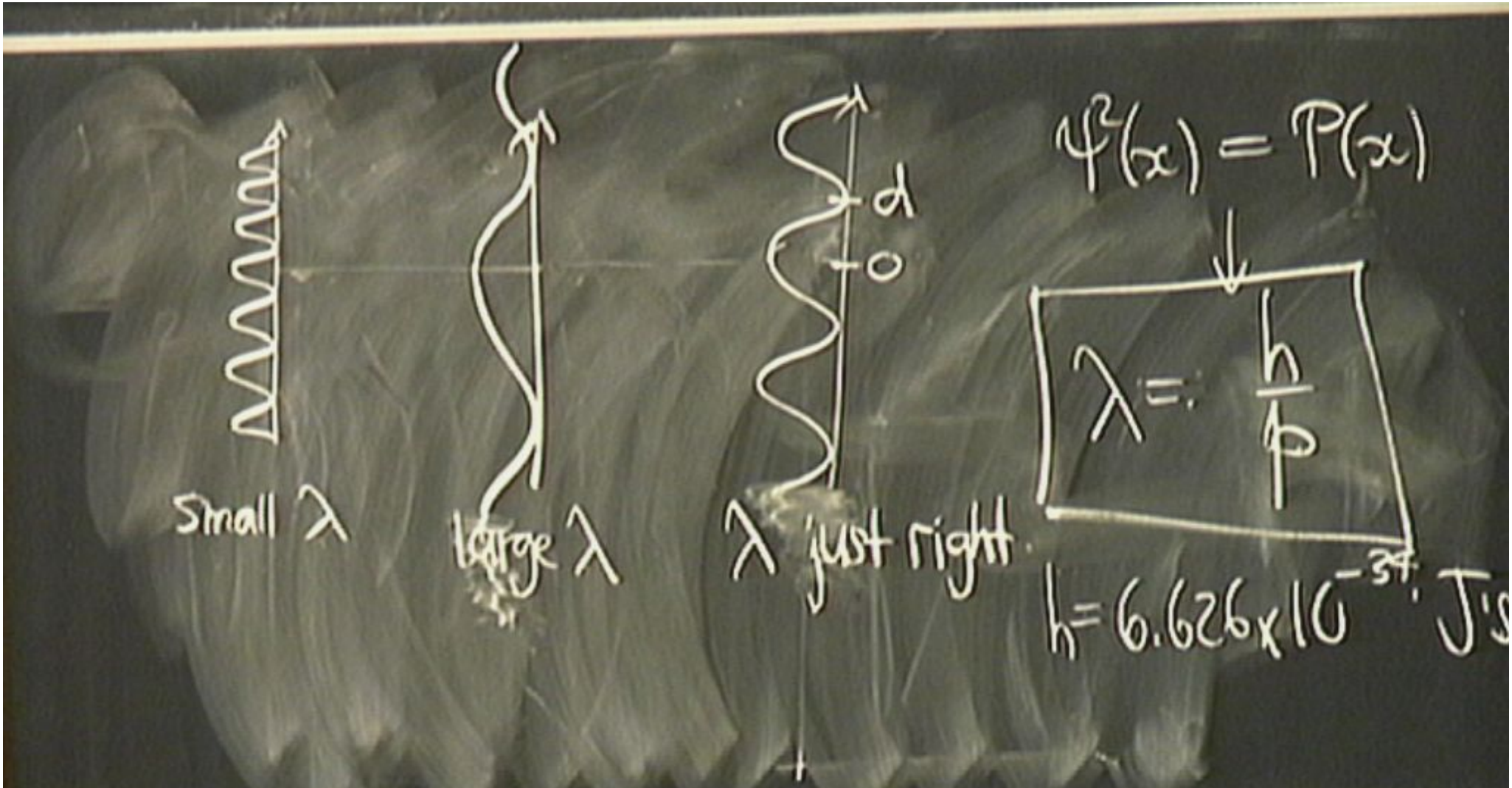

Interference
x
O

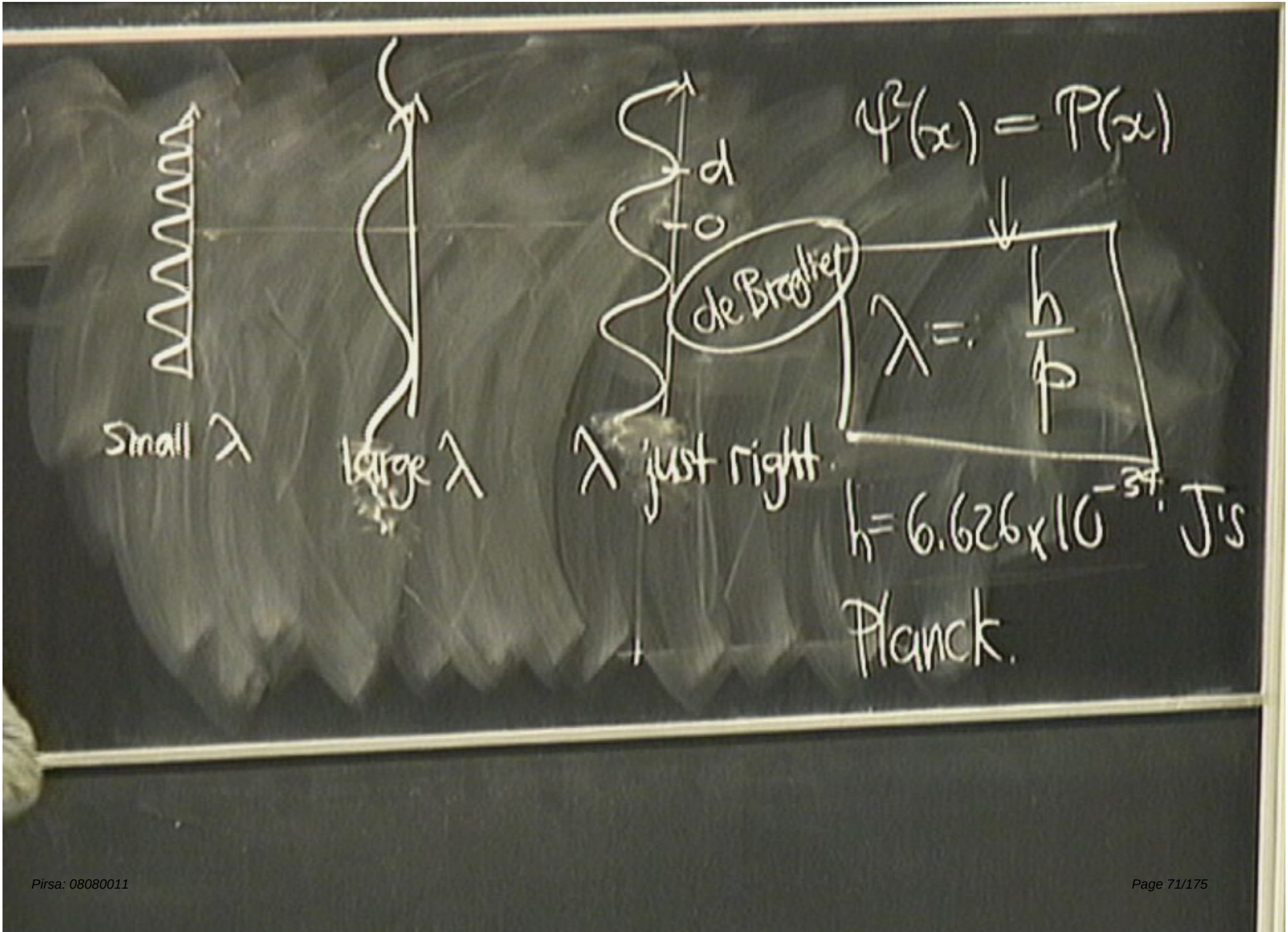

Interference
x
O

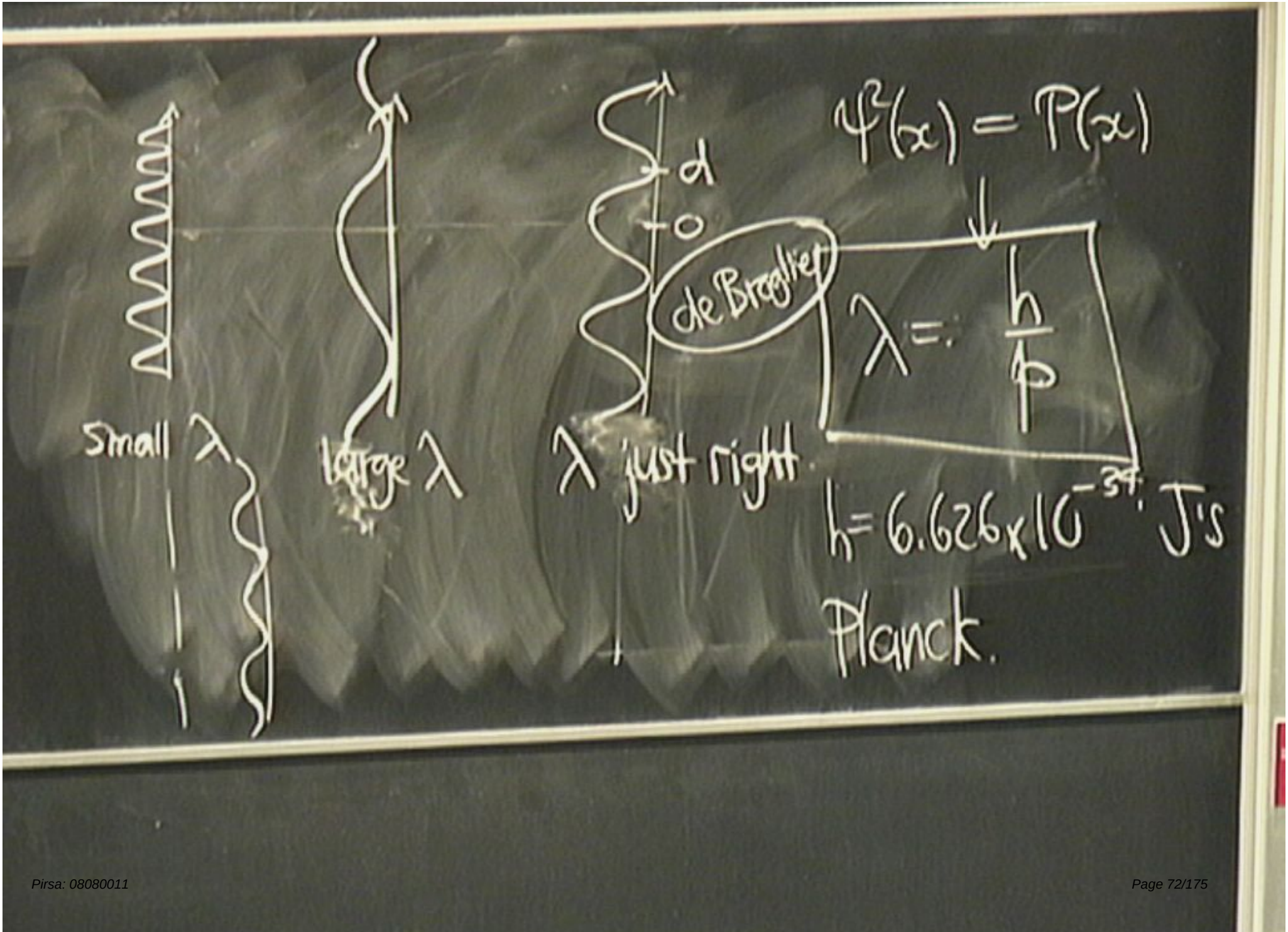

Small λ
large λ

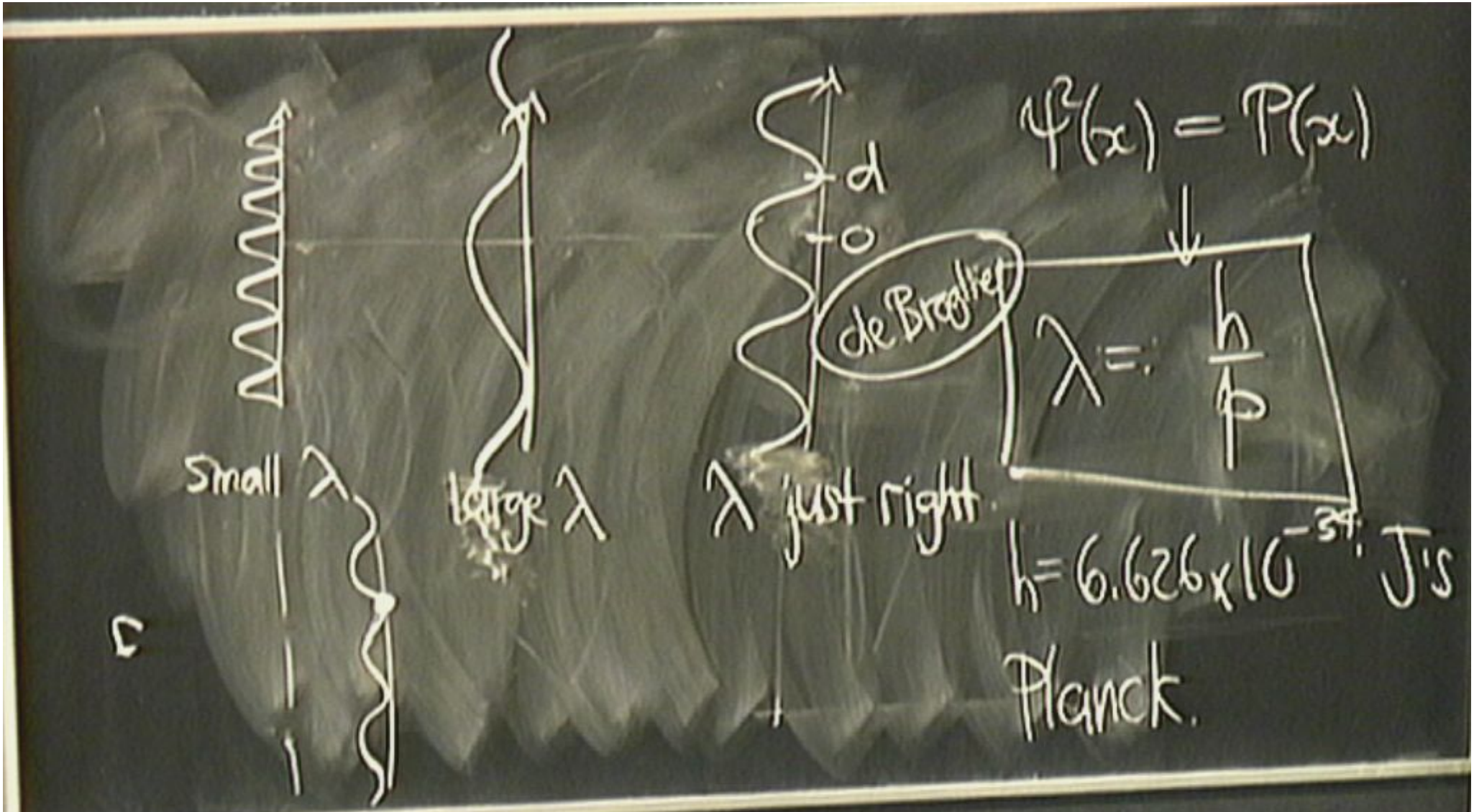

d
0
Small λ
large λ
λ just right.

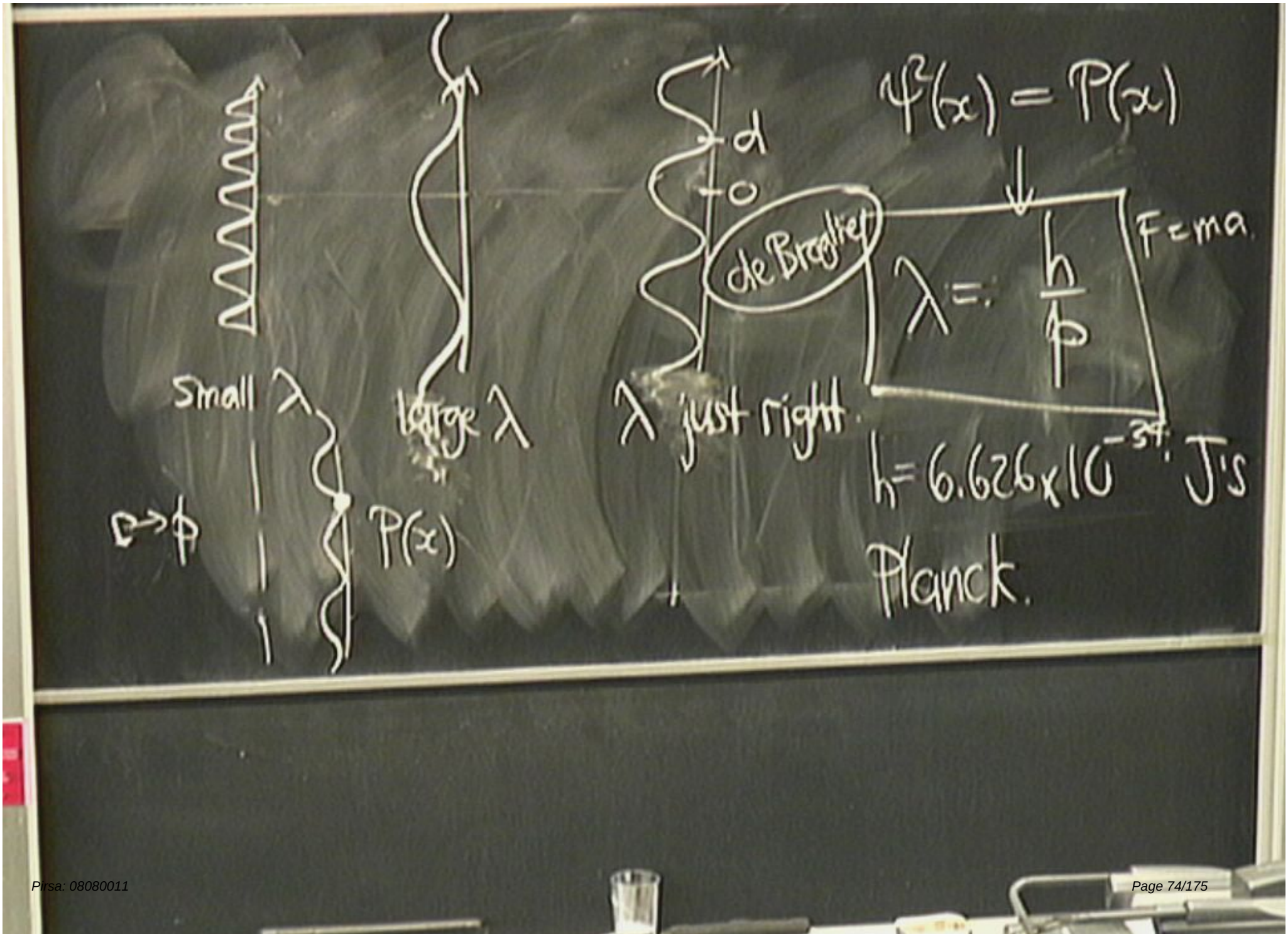

d
0
Small λ
large λ
λ just right.

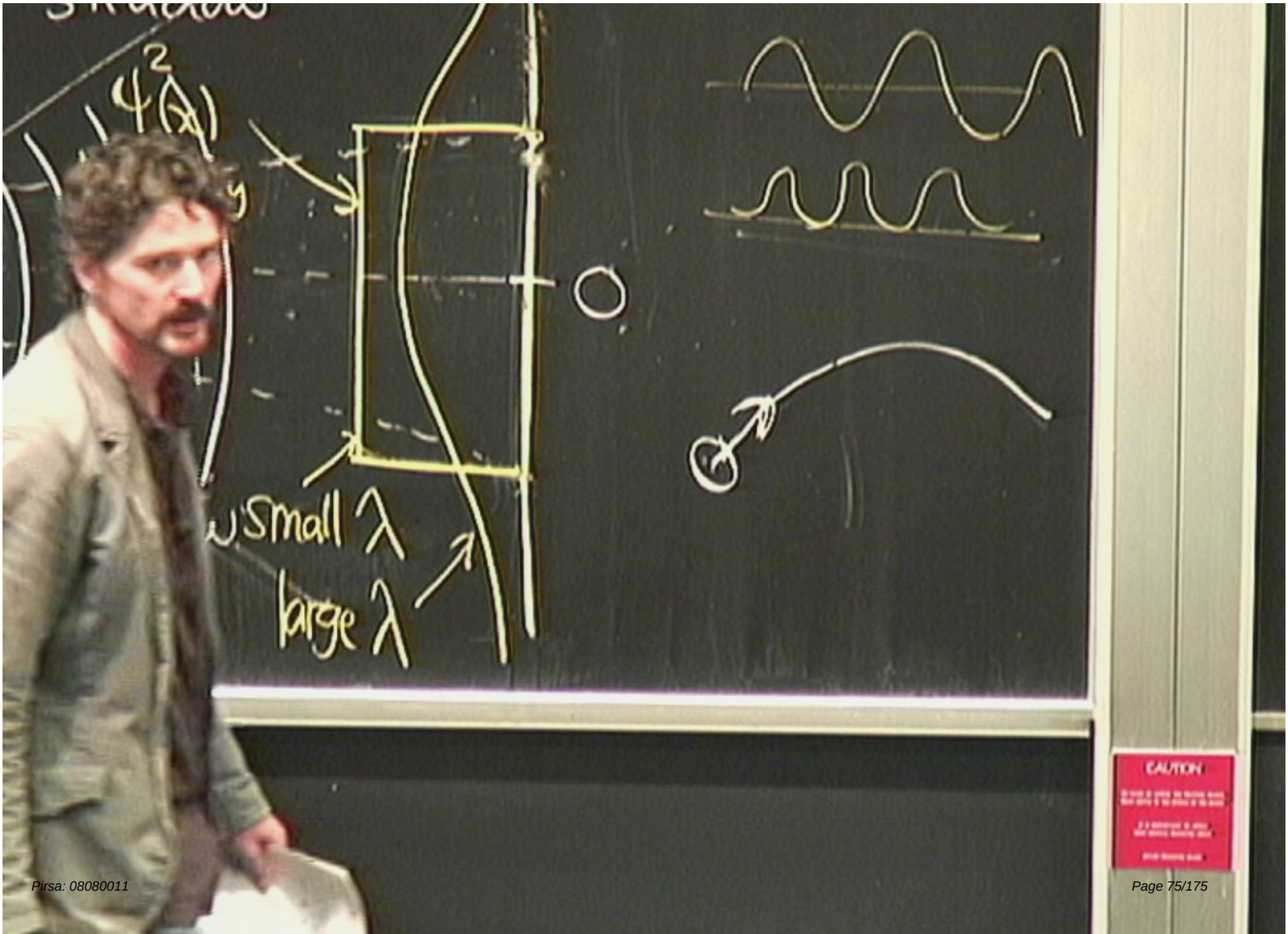

d
0
$\psi^2(x) = P(x)$
$\lambda = \frac{h}{p}$
Small λ
large λ
λ just right
$h = 6.626 \times 10^{-34}$ J·s

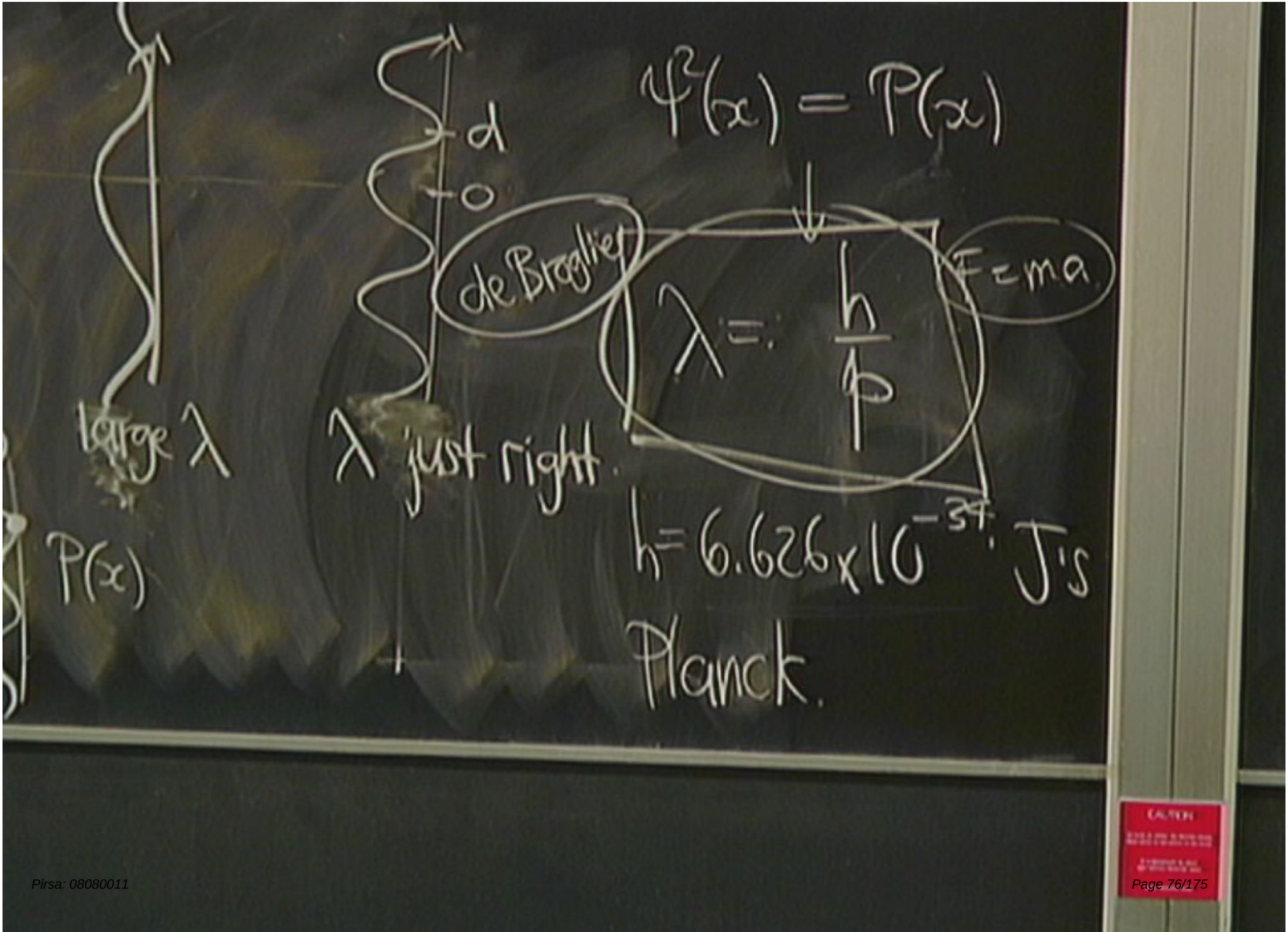

small λ
large λ
d
0
λ "just right"
de Broglie
$\psi^2(x) = P(x)$
$\lambda = \frac{h}{p}$
$h = 6.626 \times 10^{-34}$ J's
Planck.

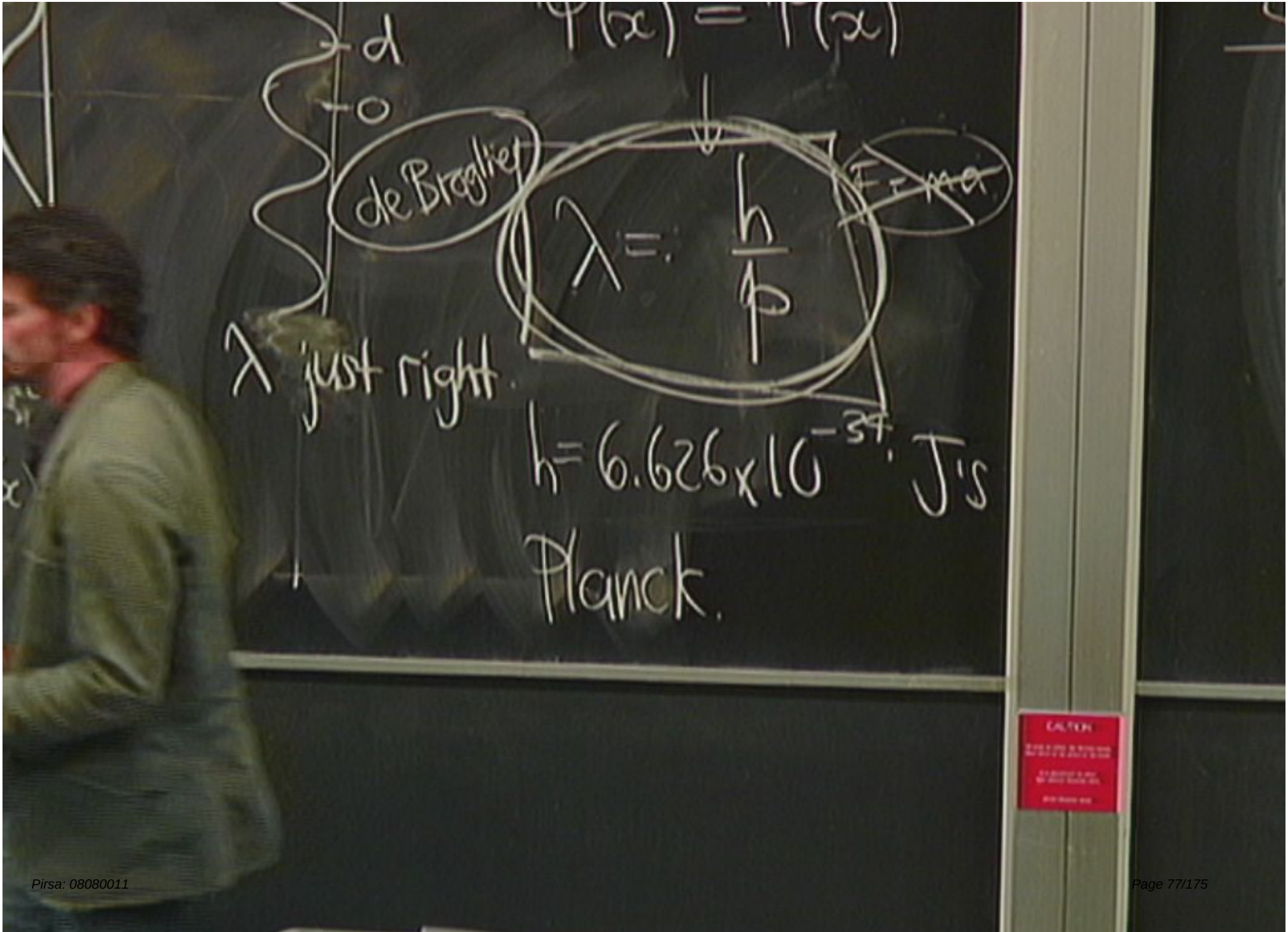

small λ
large λ
d
0
λ just right.
de Broglie
$\psi^2(x) = P(x)$
$\lambda = \frac{h}{p}$
$h = 6.626 \times 10^{-34}$ J's
Planck.

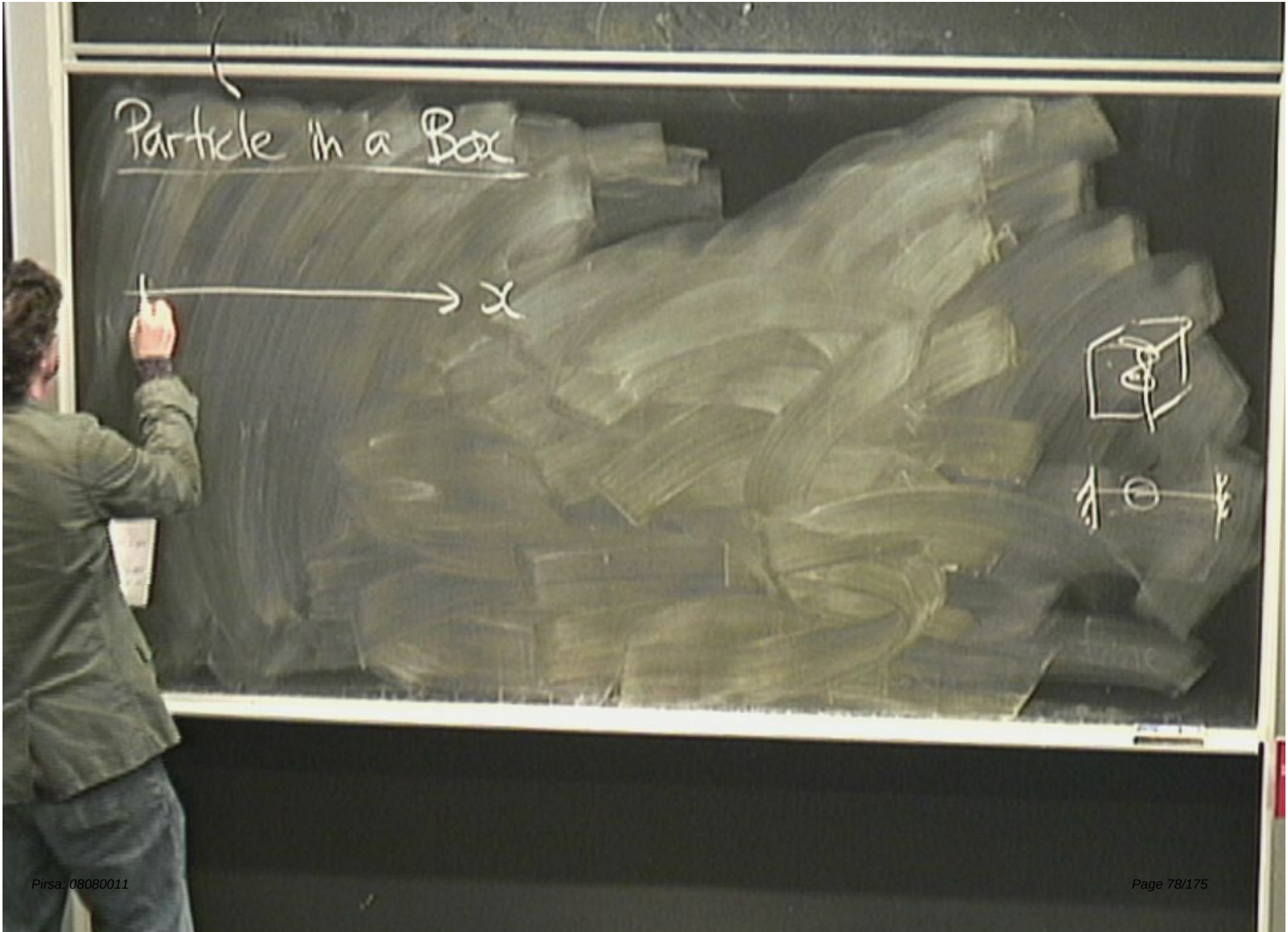

small λ
large λ
d
0
de Broglie
λ just right
$\psi^2(x) = P(x)$
$\lambda = \frac{h}{p}$
$h = 6.626 \times 10^{-34}$ J's
Planck.

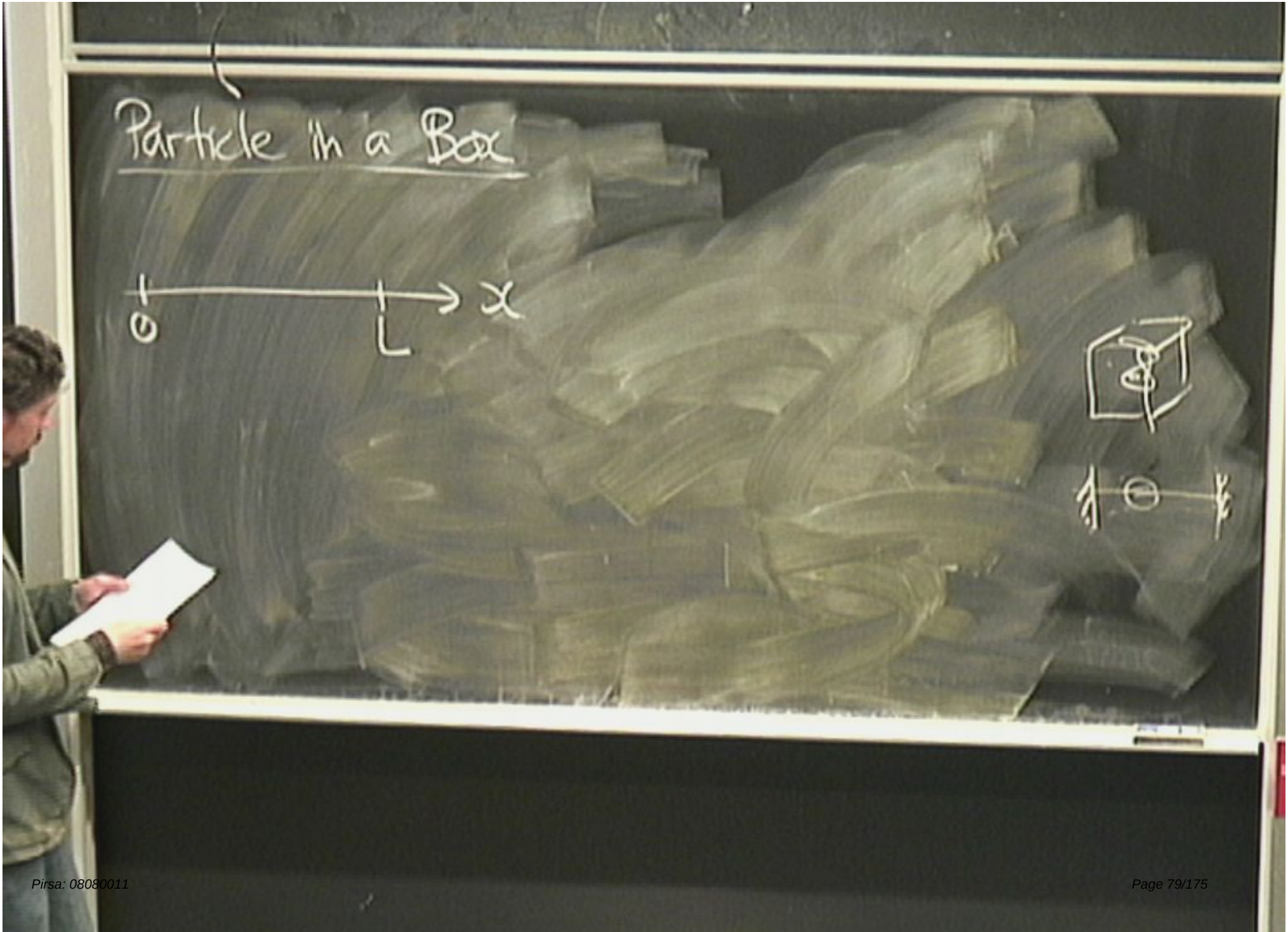

small λ
large λ
P(x)
d
0
de Broglie
λ just right
ψ²(x) = P(x)
λ = h/p
F=ma
h = 6.626 x 10⁻³⁴ J's
Planck.

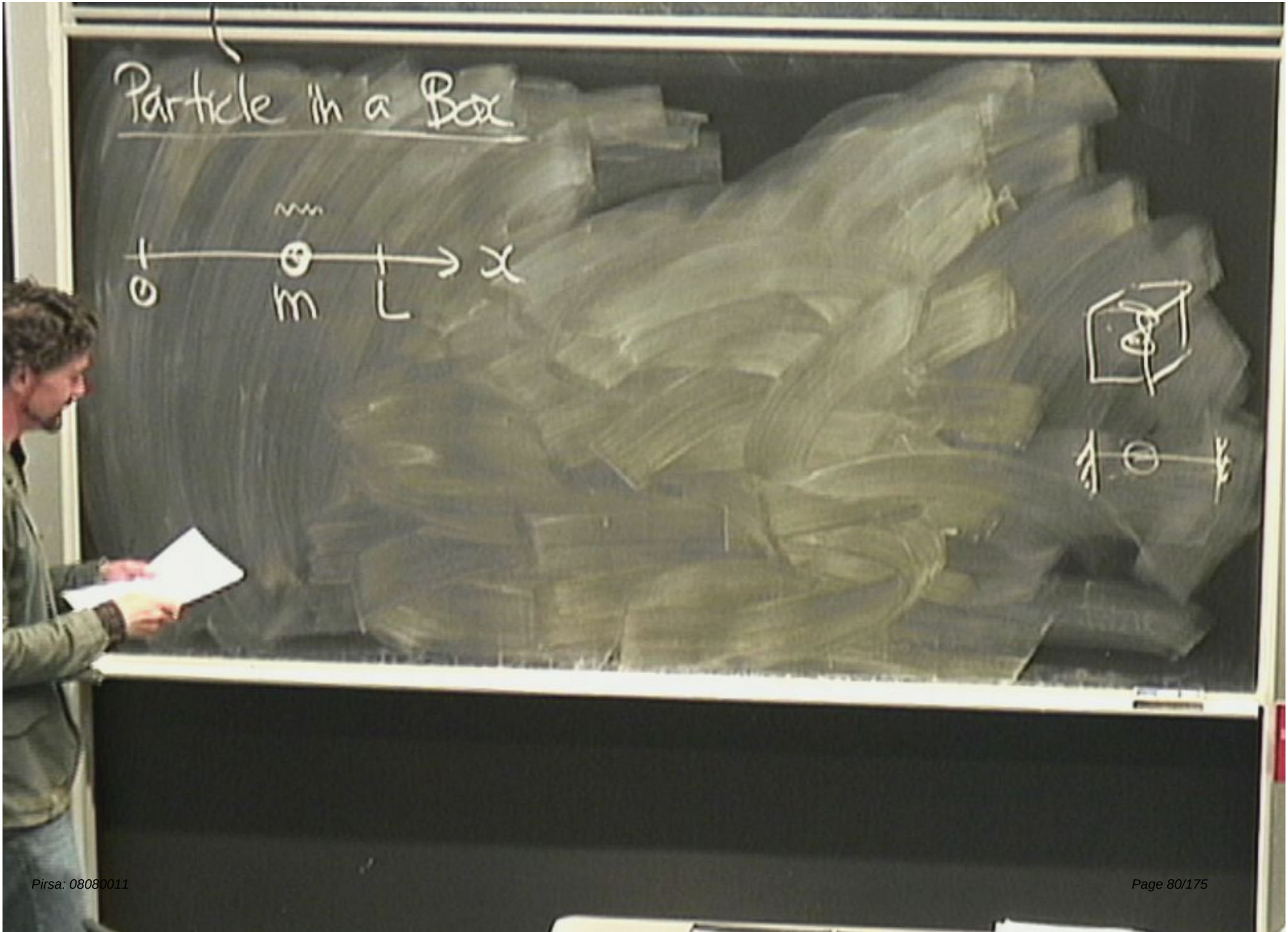

small λ
large λ
CAUTION


large λ
d
0
λ just right.
$\Psi^2(x) = P(x)$
de Broglie
$\lambda = \frac{h}{p}$
F = ma
P(x)
$h = 6.626 \times 10^{-34}$ J's
Planck.

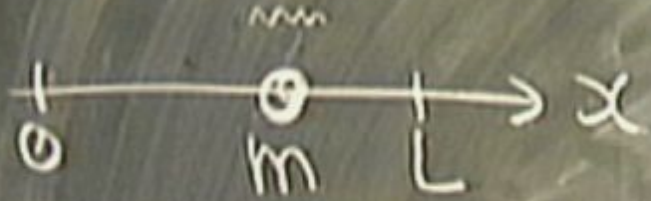

d
0
de Broglie
$\lambda = \frac{h}{p}$
$E = mc^2$
λ just right.
$h = 6.626 \times 10^{-34}$ J's
Planck.


Particle in a Box
x


Particle in a Box
0
L
x

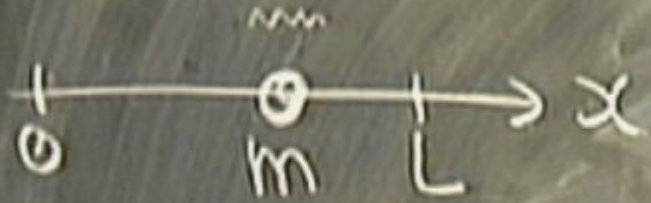

Particle in a Box
0
m
L
x

Particle in a Box



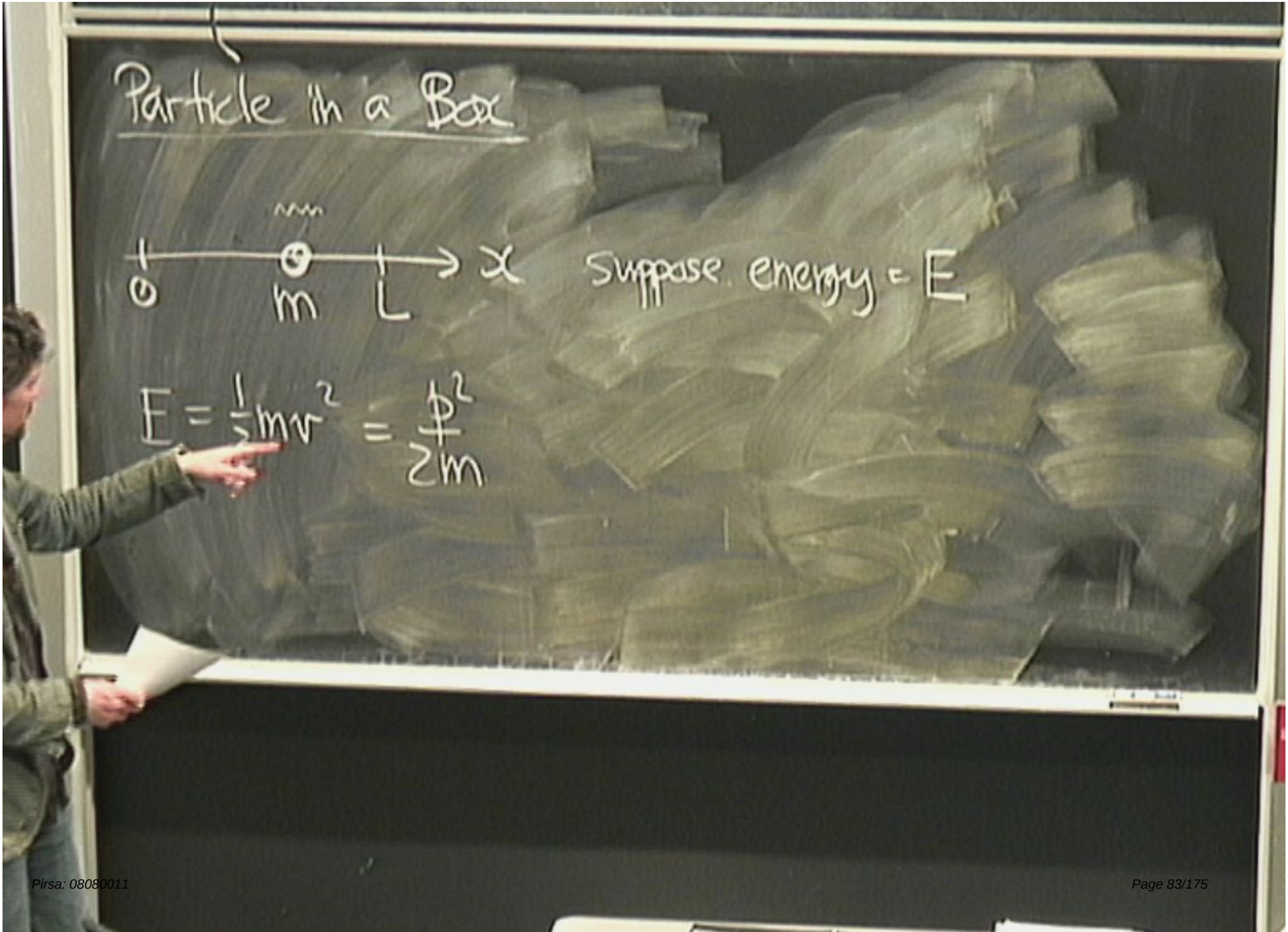
Suppose energy = E

Particle in a Box

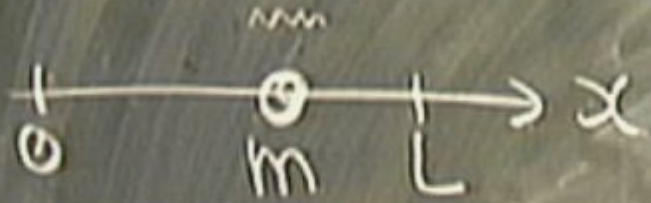


Suppose energy = E

$$E = \frac{1}{2}mv^2 =$$

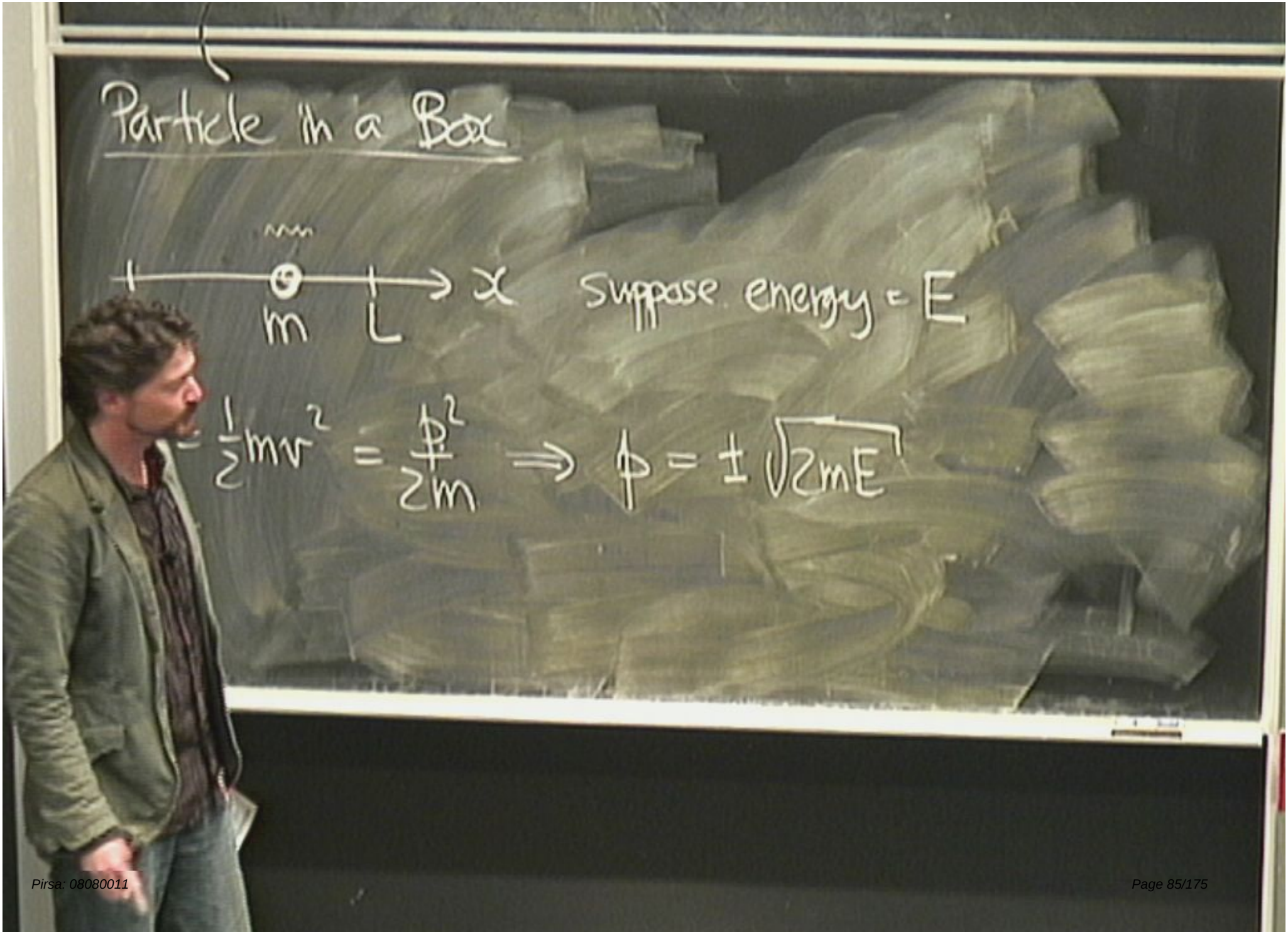

Particle in a Box
0
m
L
x
Suppose energy = E
$E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

Particle in a Box

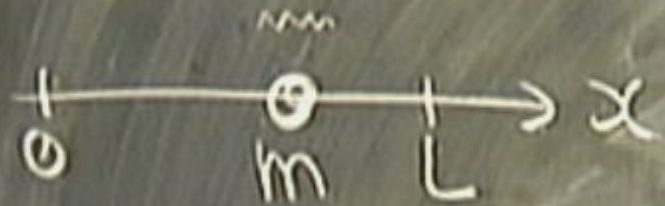


Suppose energy = E

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$


Particle in a Box
m
L
x
Suppose energy = E
$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \Rightarrow p = \pm\sqrt{2mE}$

Particle in a Box



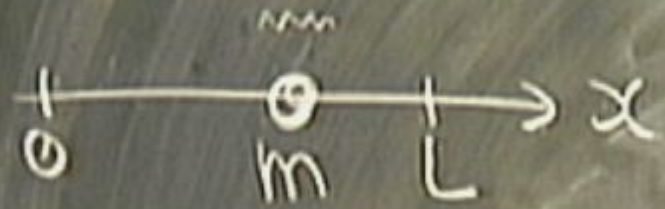
Suppose energy = E

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \Rightarrow p_x = \pm\sqrt{2mE}$$

$|A|, p_x$

p

Particle in a Box



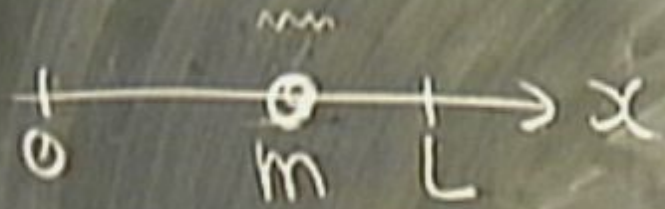
Suppose energy = E

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \Rightarrow p_x = \pm\sqrt{2mE}$$

$|A|, p_x$

p

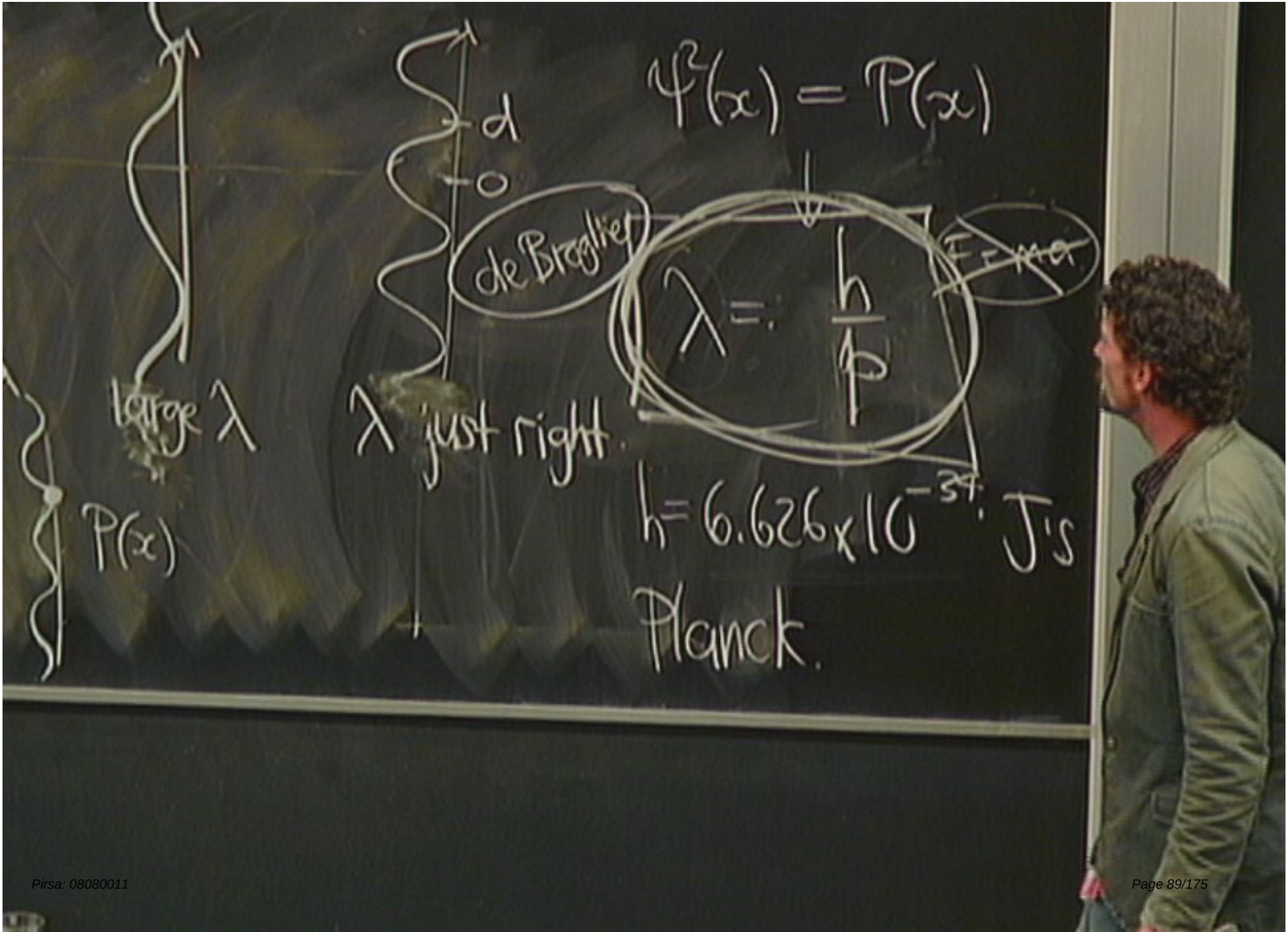
Particle in a Box



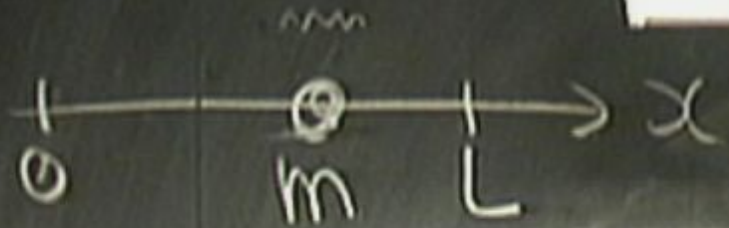
Suppose energy = E

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \Rightarrow p_x = \pm\sqrt{2mE} \quad \text{(right / left)}$$

$$|p_x|, p_x \qquad \lambda = \frac{h}{p}$$


large λ
P(x)
d
0
λ just right.
de Broglie
$\psi^2(x) = P(x)$
$\lambda = \frac{h}{p}$
$E = mc^2$
$h = 6.626 \times 10^{-34}$ J's
Planck.

Particle in a

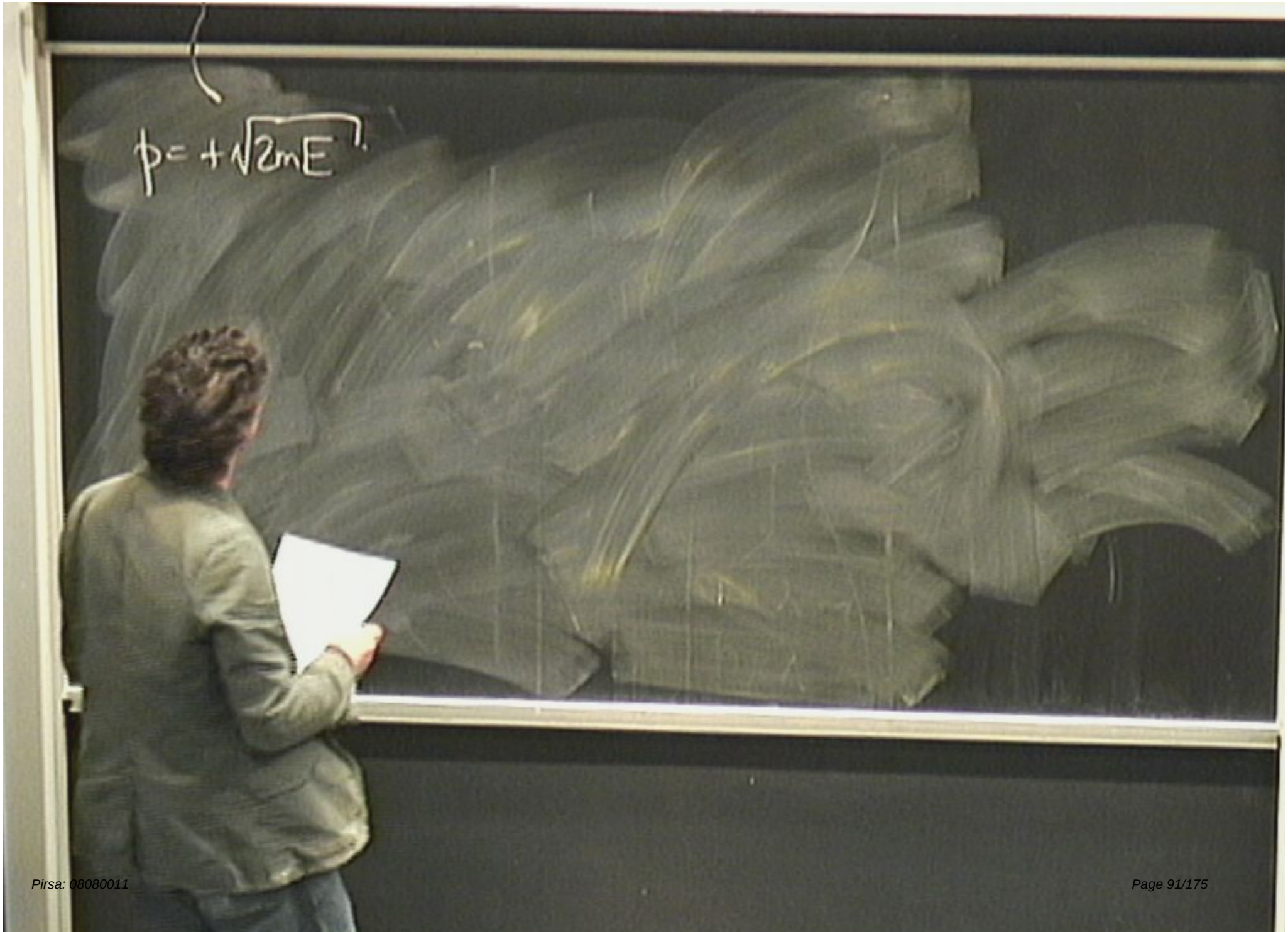


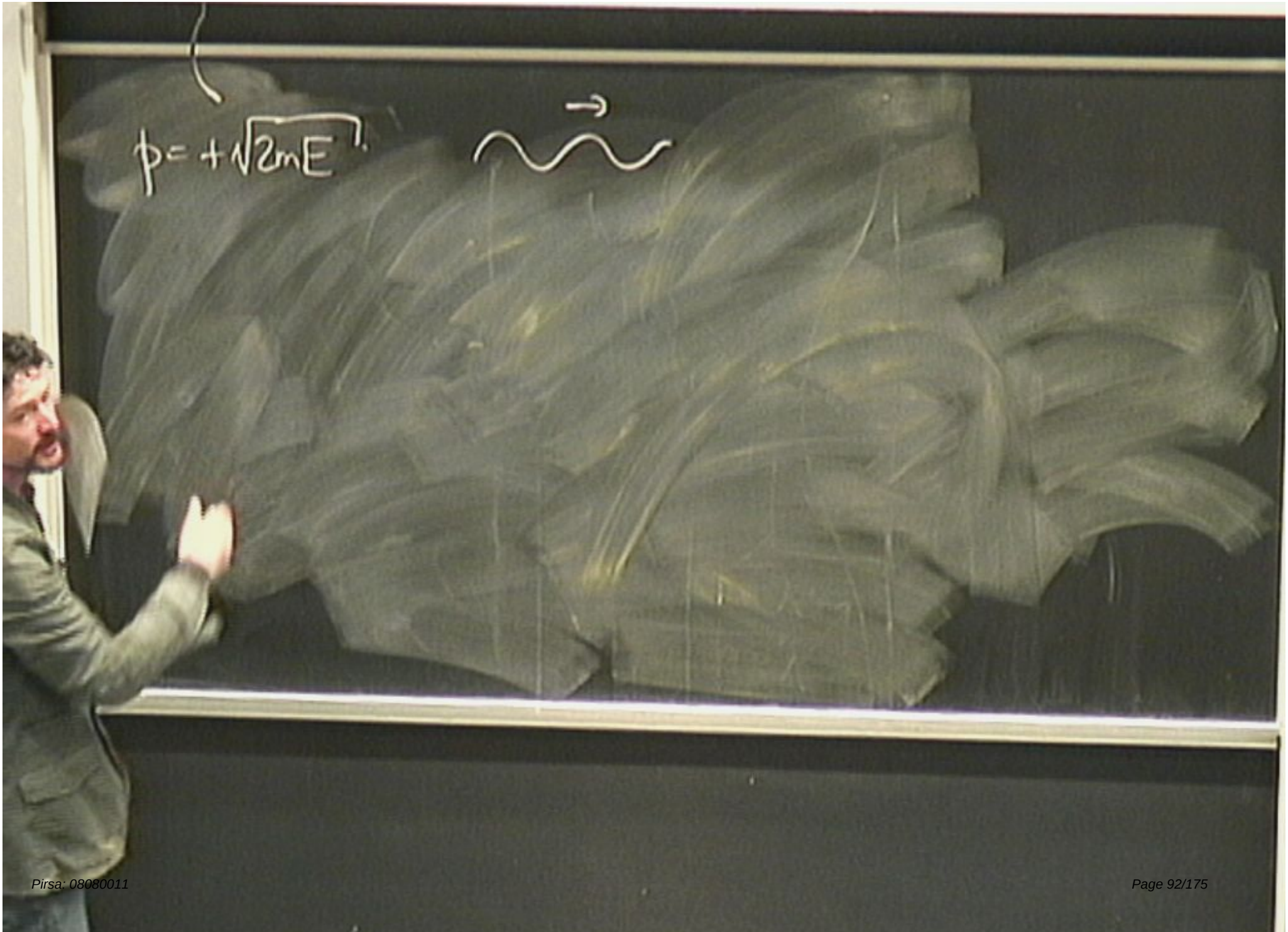
Suppose energy = E

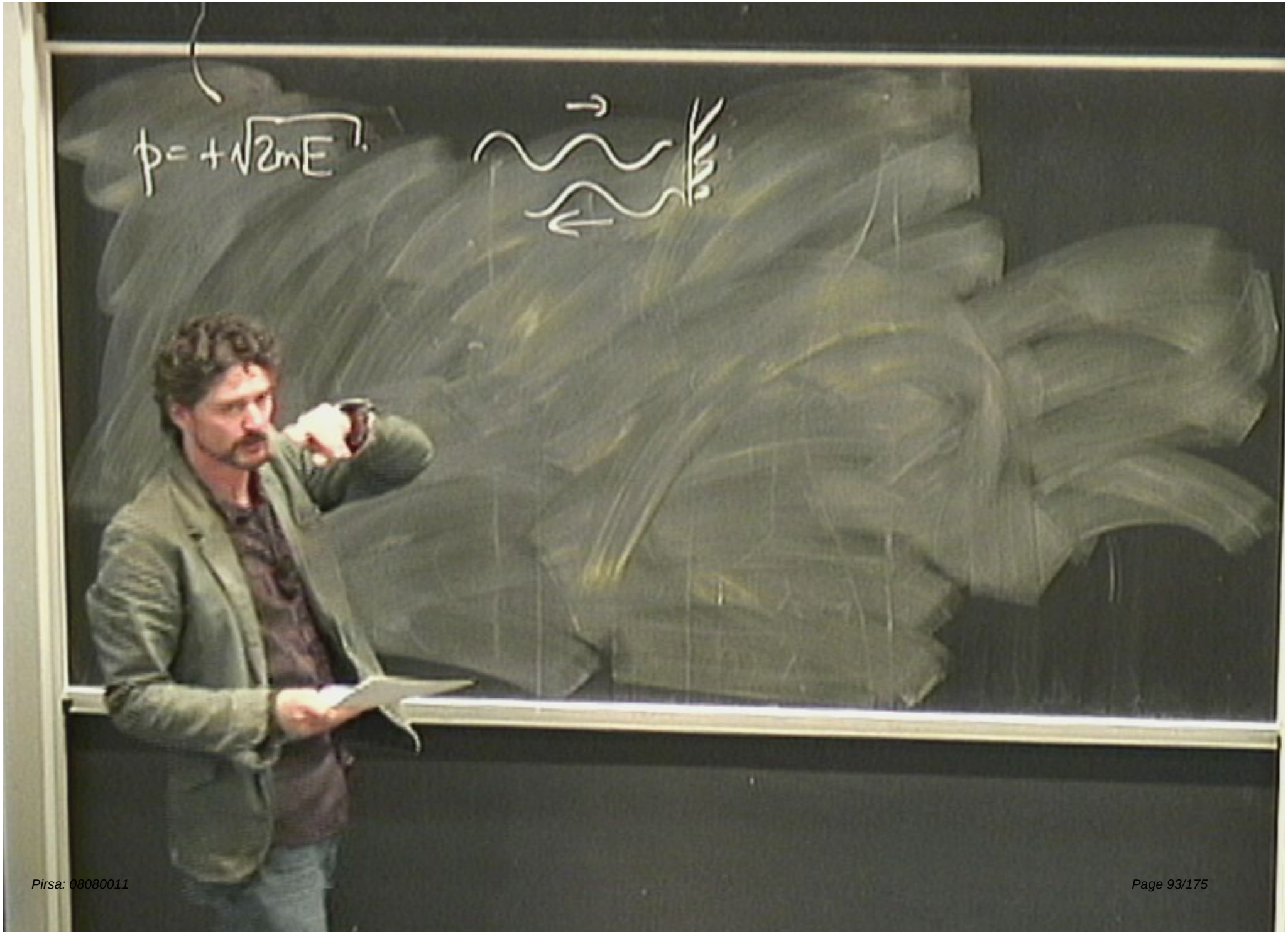
$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \Rightarrow p_x = \pm\sqrt{2mE} \quad \text{(right / left)}$$

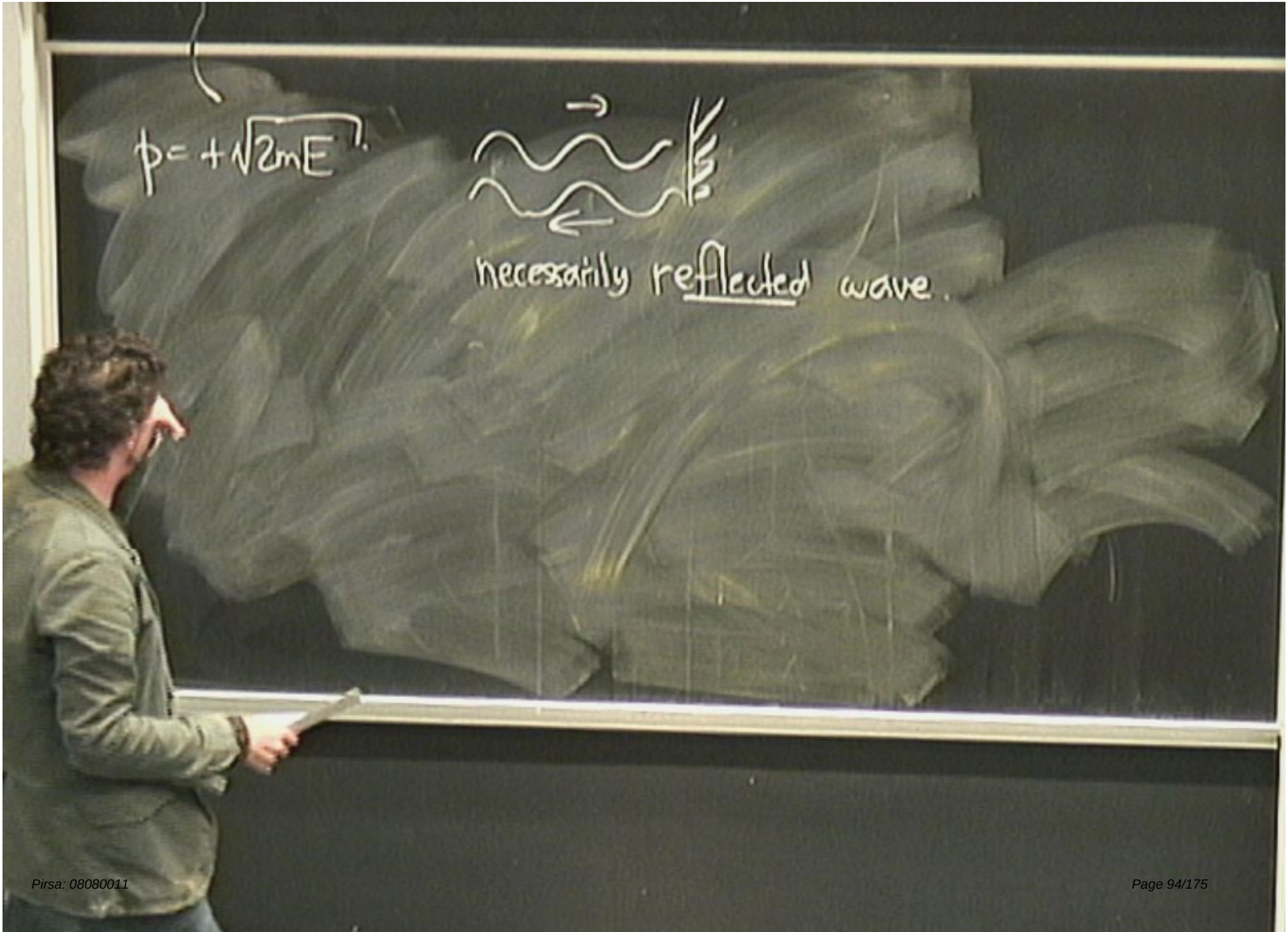
$|p_x|$, p_x

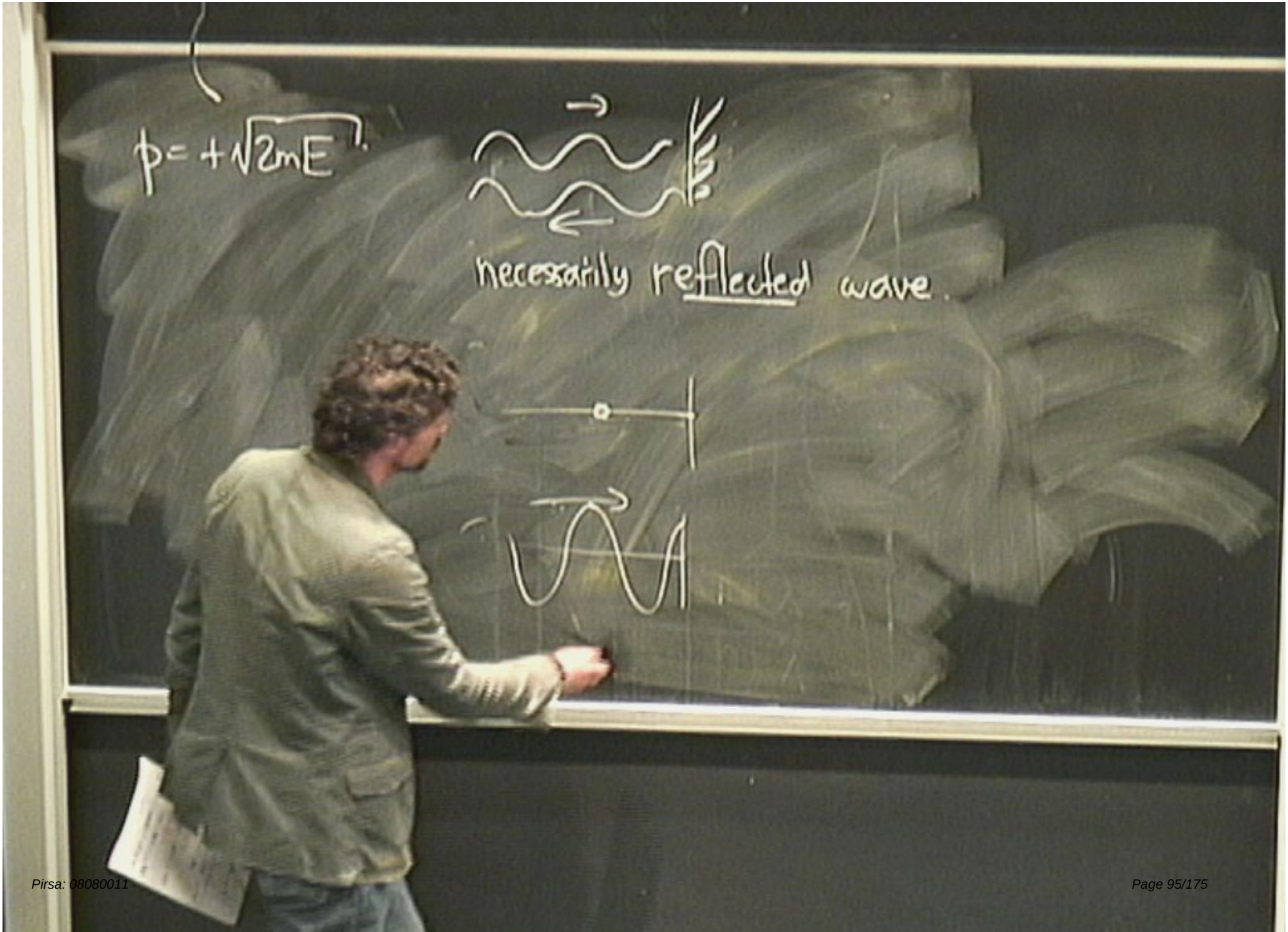
$$\lambda = \frac{h}{\sqrt{2mE}}$$


$p = +\sqrt{2mE}$


$p = +\sqrt{2mE}$


p = +√2mE


$p = +\sqrt{2mE}$
necessarily reflected wave.


$p = +\sqrt{2mE}$
necessarily reflected wave.

$p = +\sqrt{2mE}$

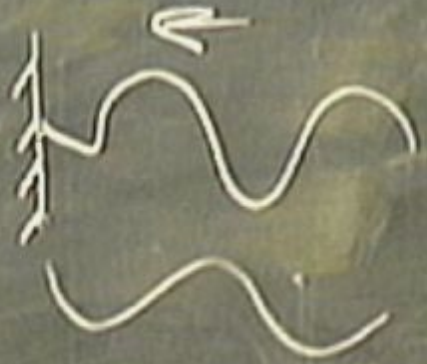
necessarily reflected wave.

$p = -\sqrt{2mE}$

$p = +\sqrt{2mE}$

necessarily reflected wave.

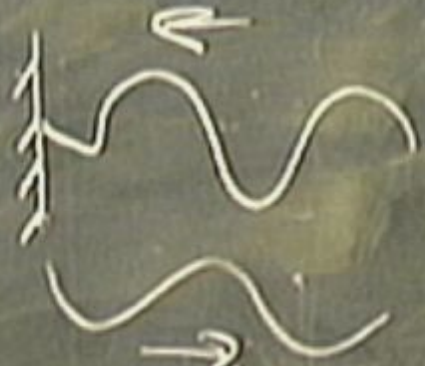
$p = -\sqrt{2mE}$



$p = +\sqrt{2mE}$

necessarily reflected wave.

$p = -\sqrt{2mE}$



forced to use a superposition of right and left waves.

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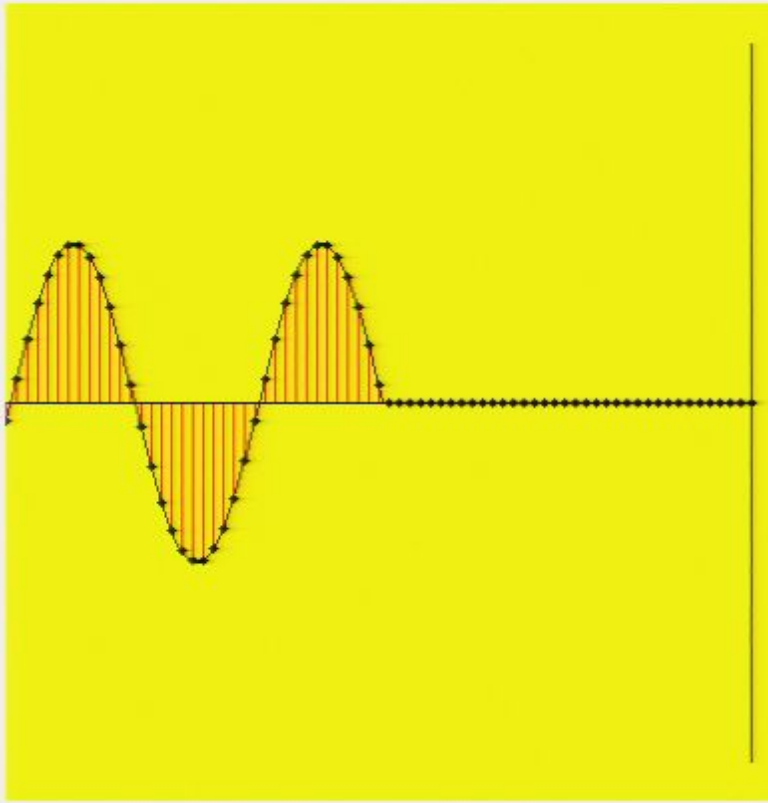

Reflection

- from a fixed end
- from a free end

Reset

Pause

Slow motion

- Animation
- Single steps T/8

- Incidenting wave
- Reflected wave
- Resultant standing wave

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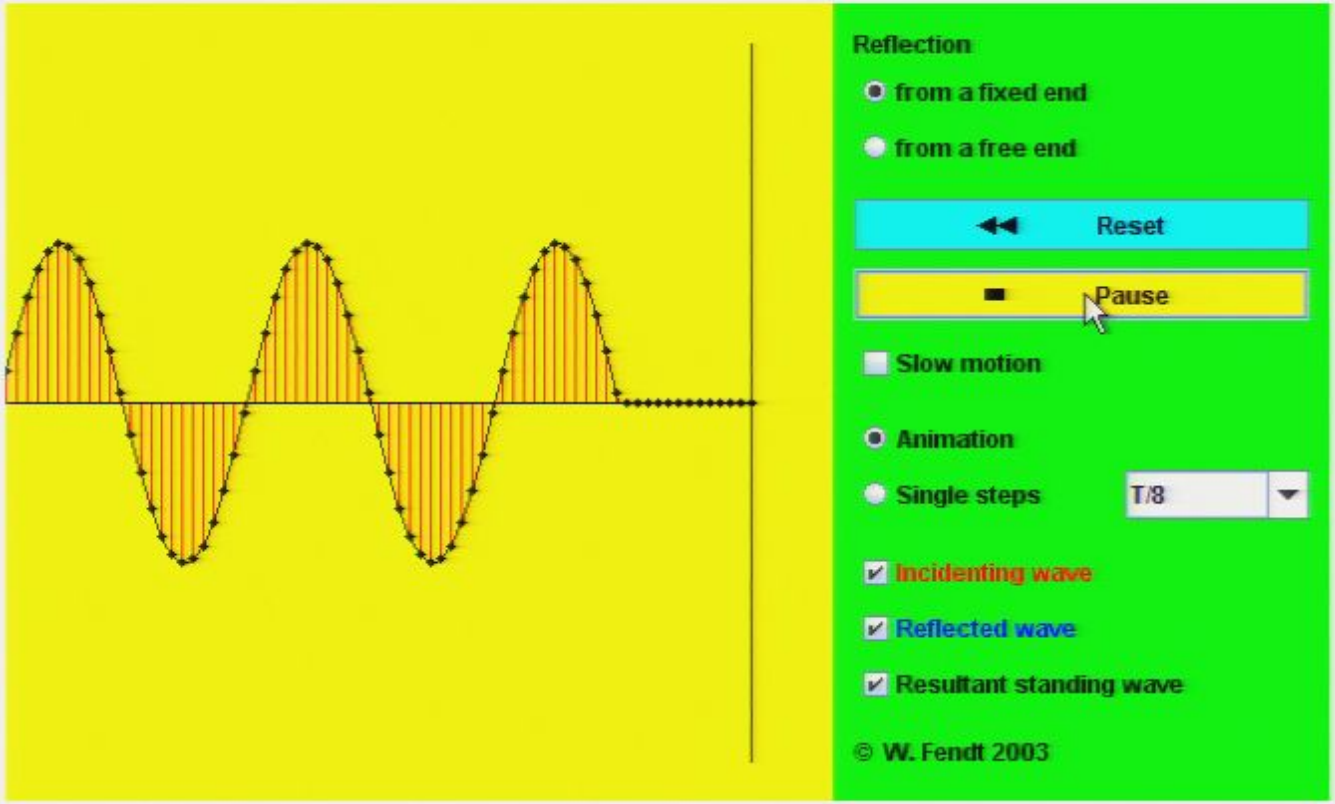

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Page Tools

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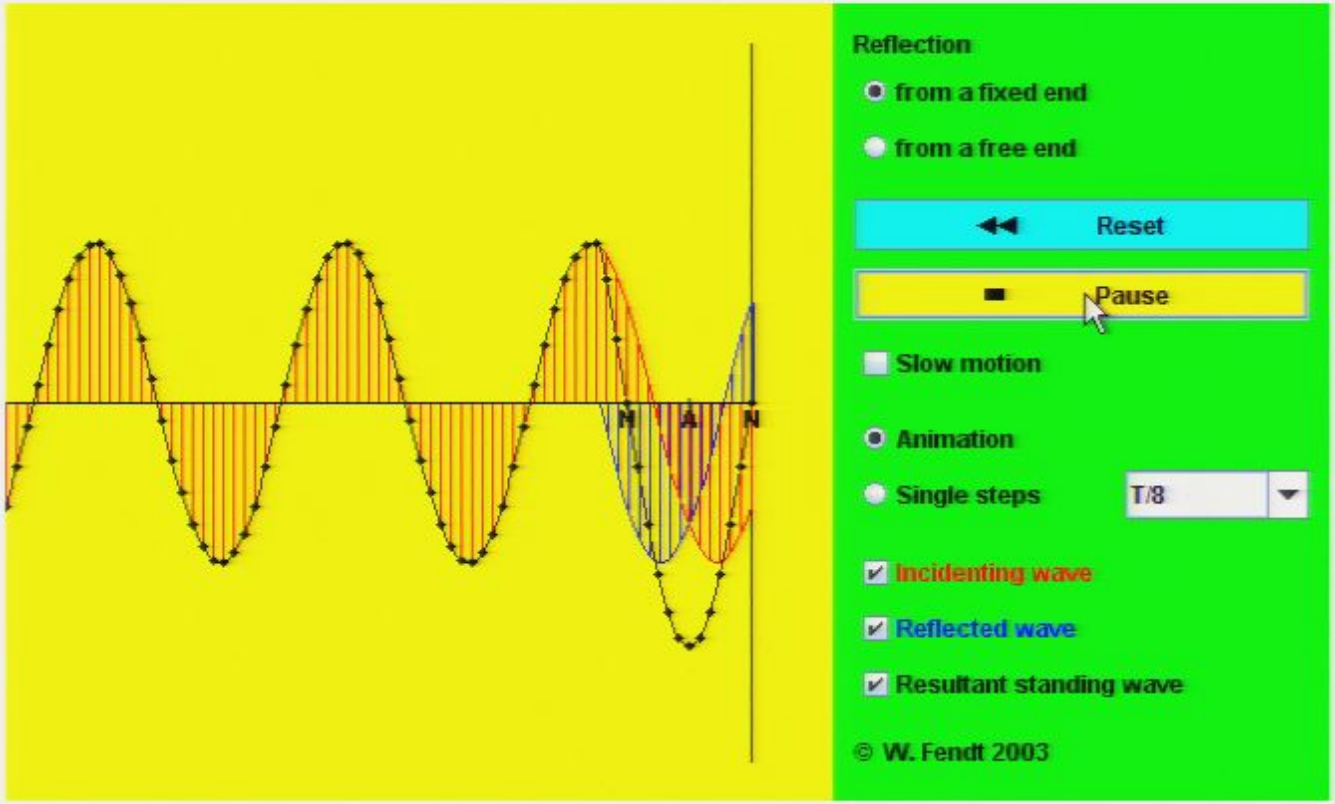

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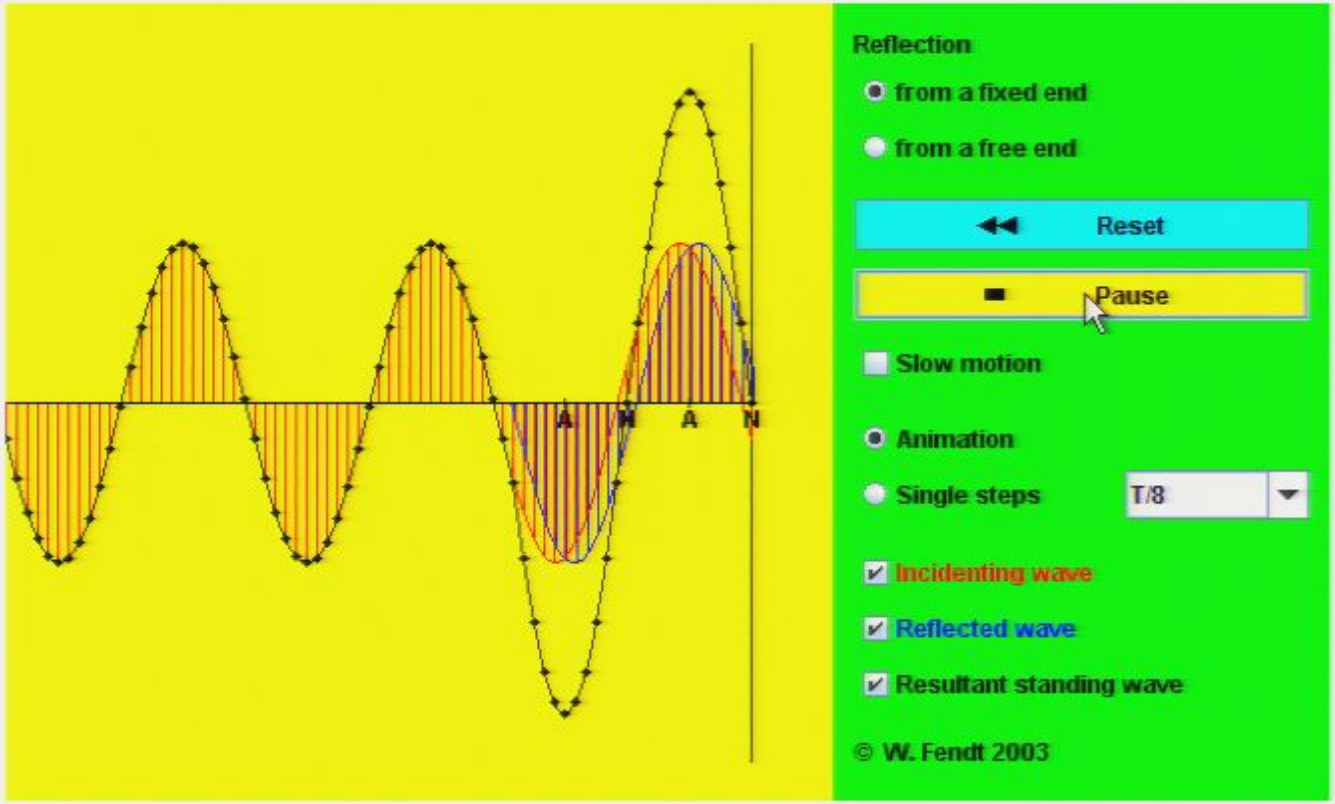

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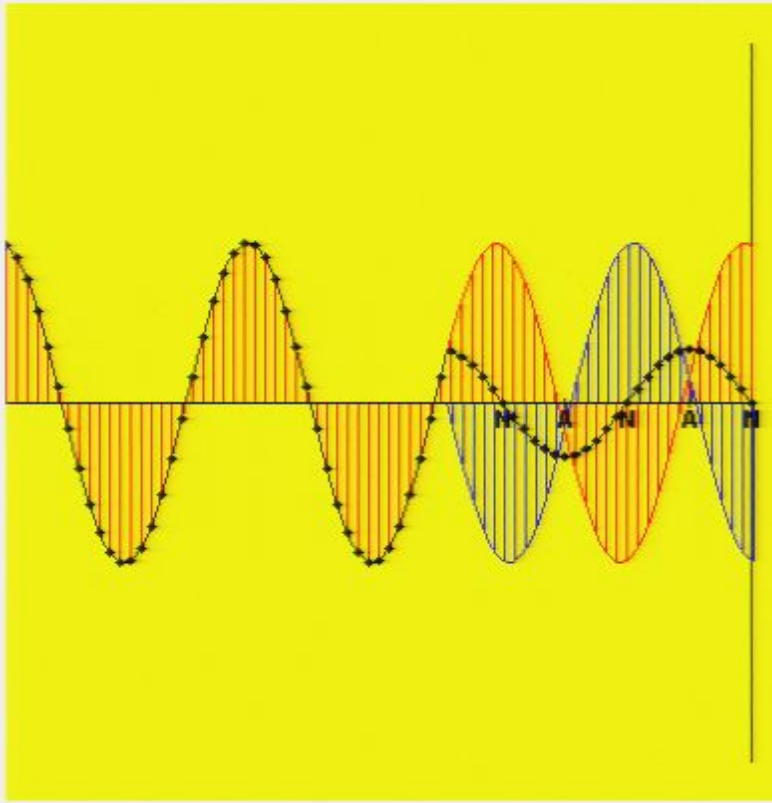
(Explanation by Superposition with the Reflected Wave)



Reflection

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Reset

Pause

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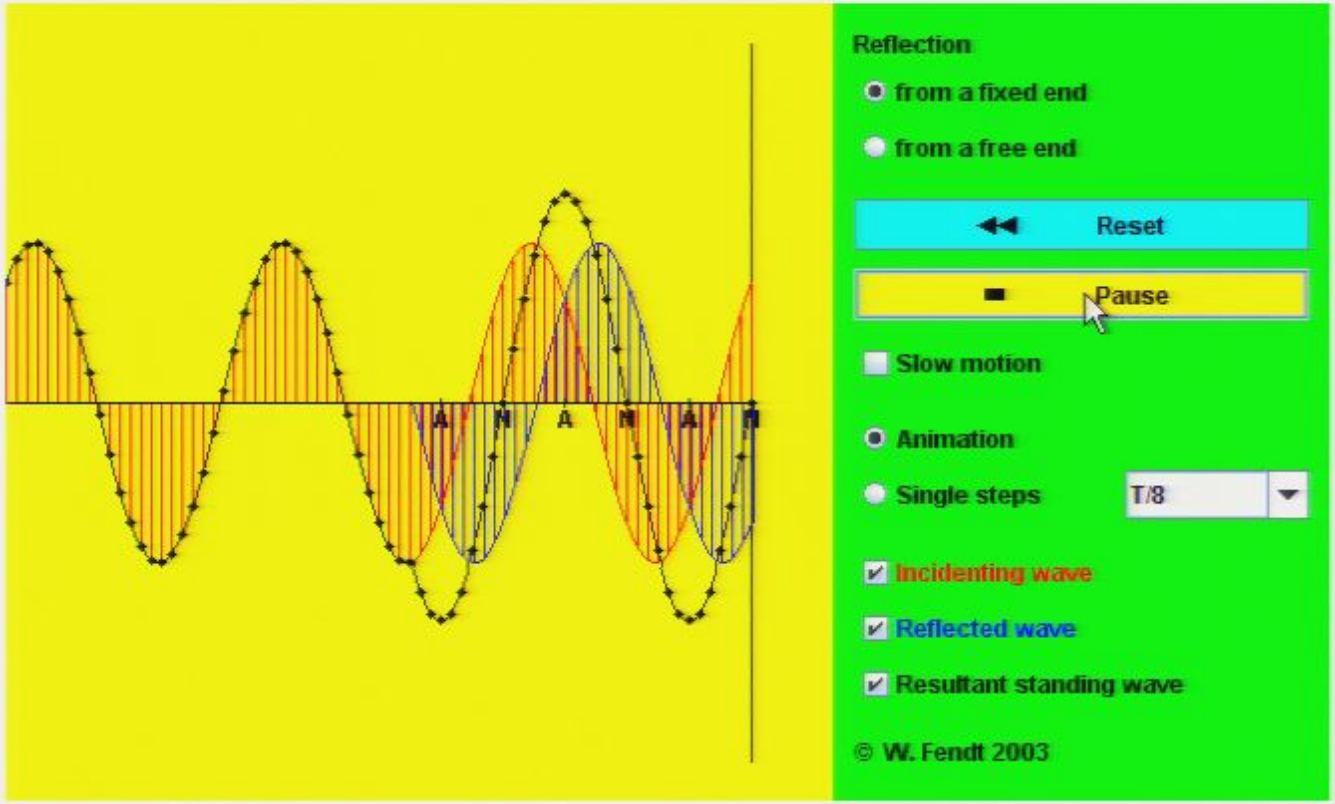

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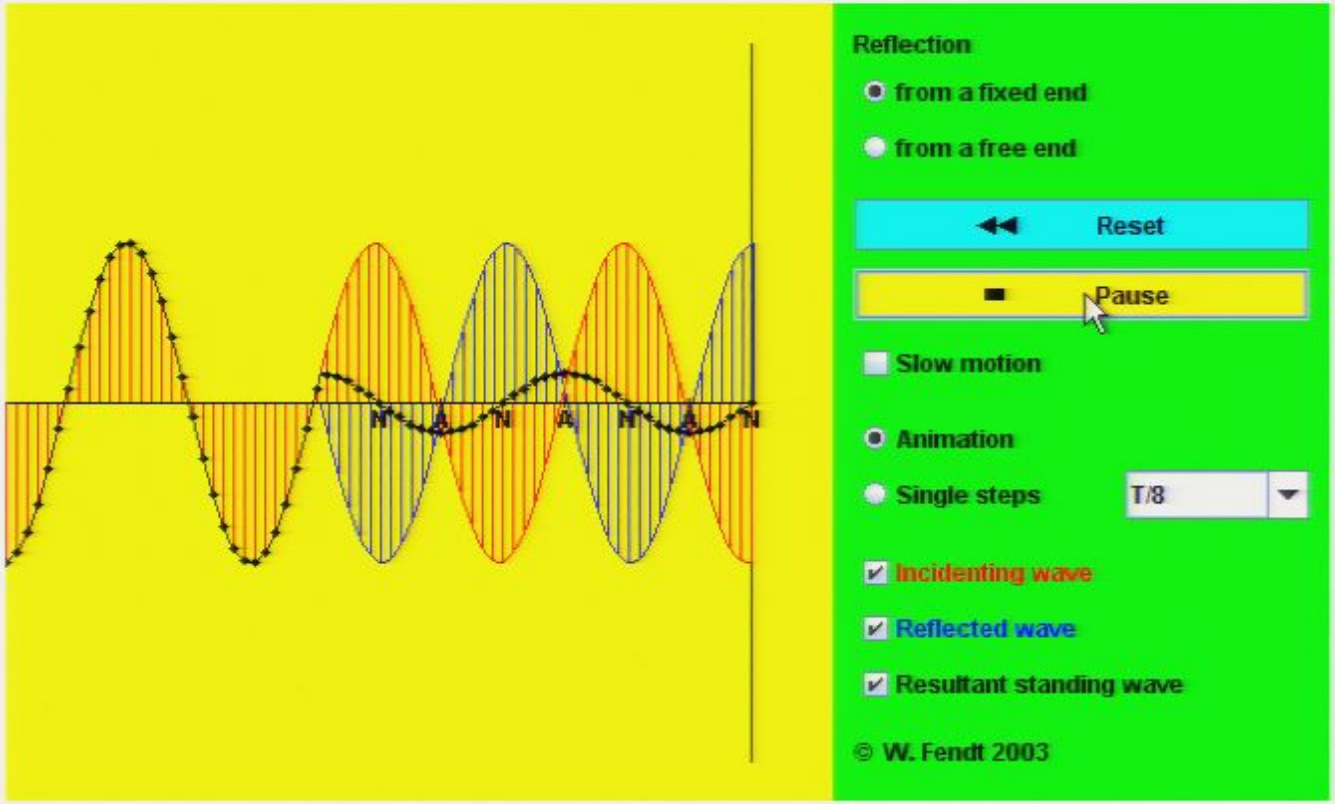

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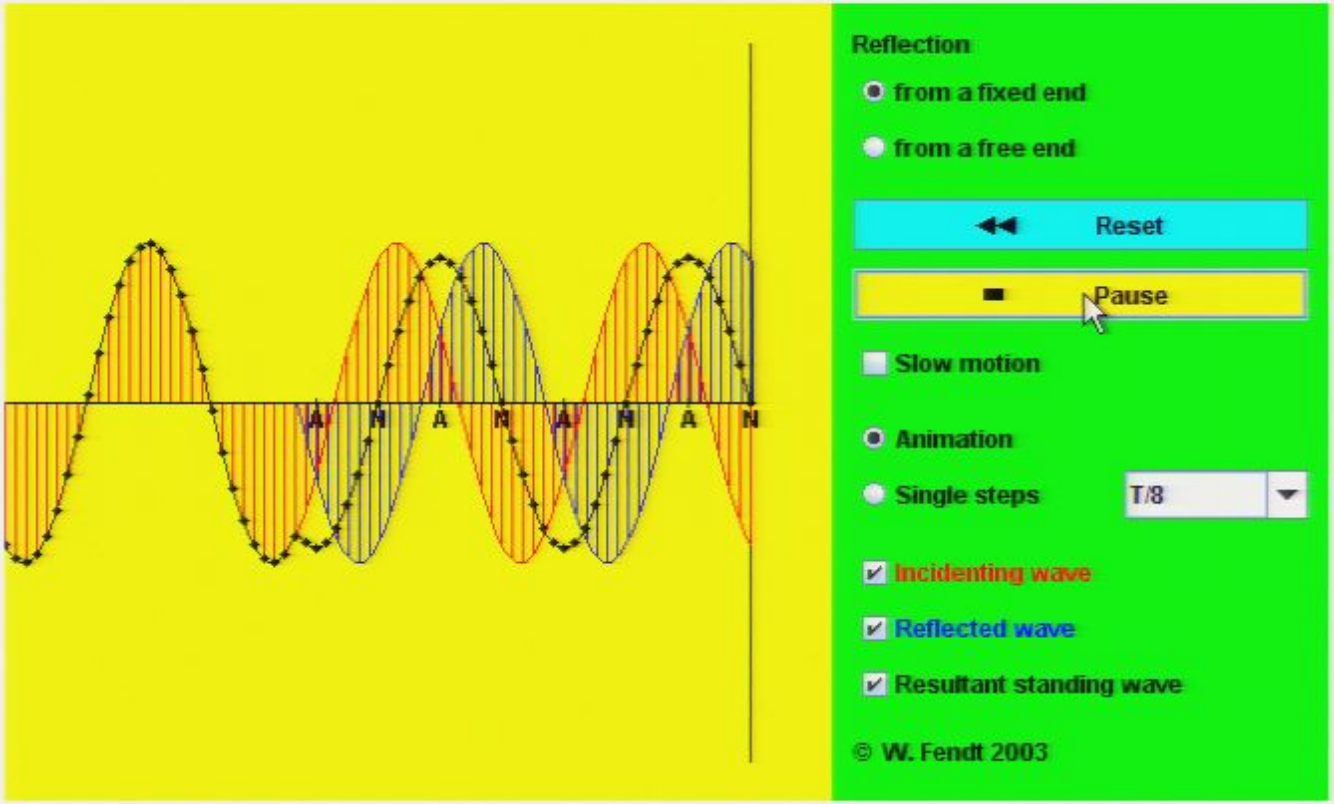

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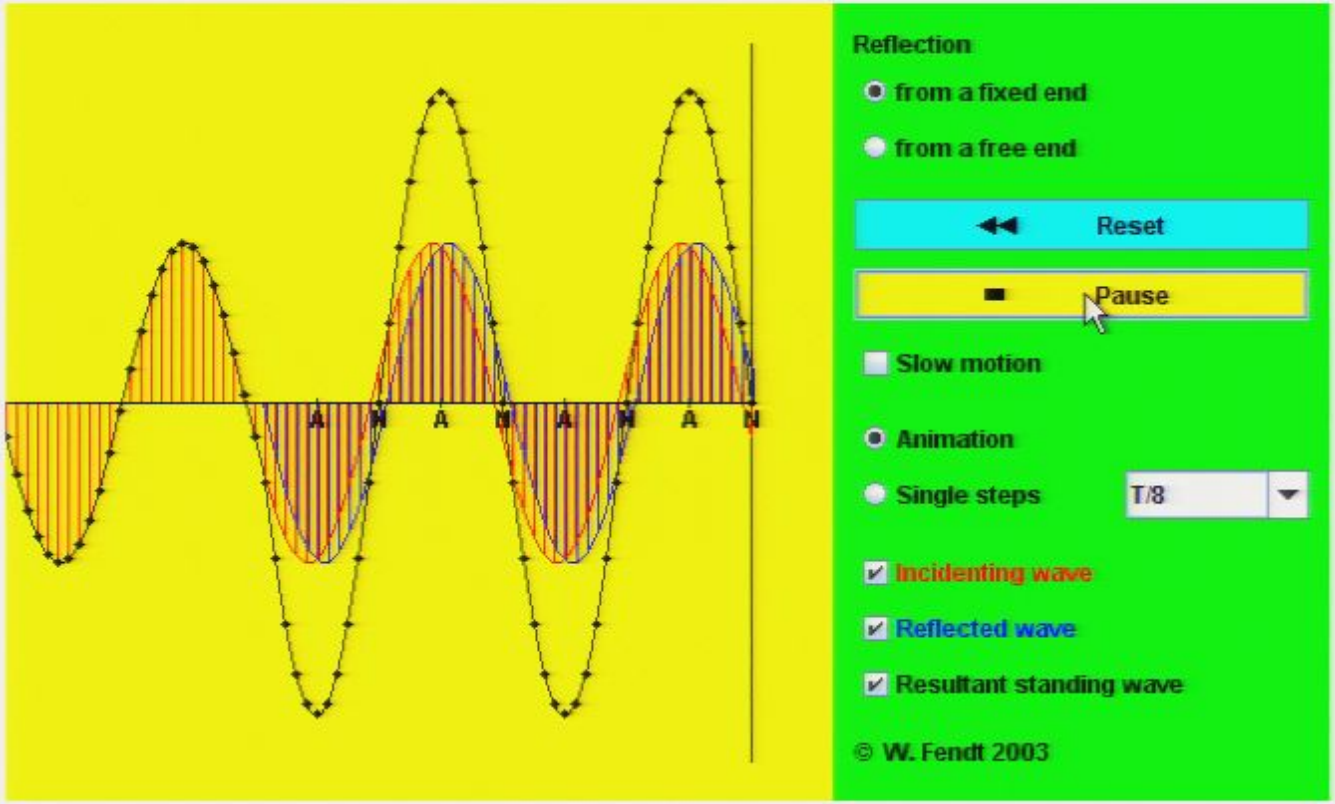

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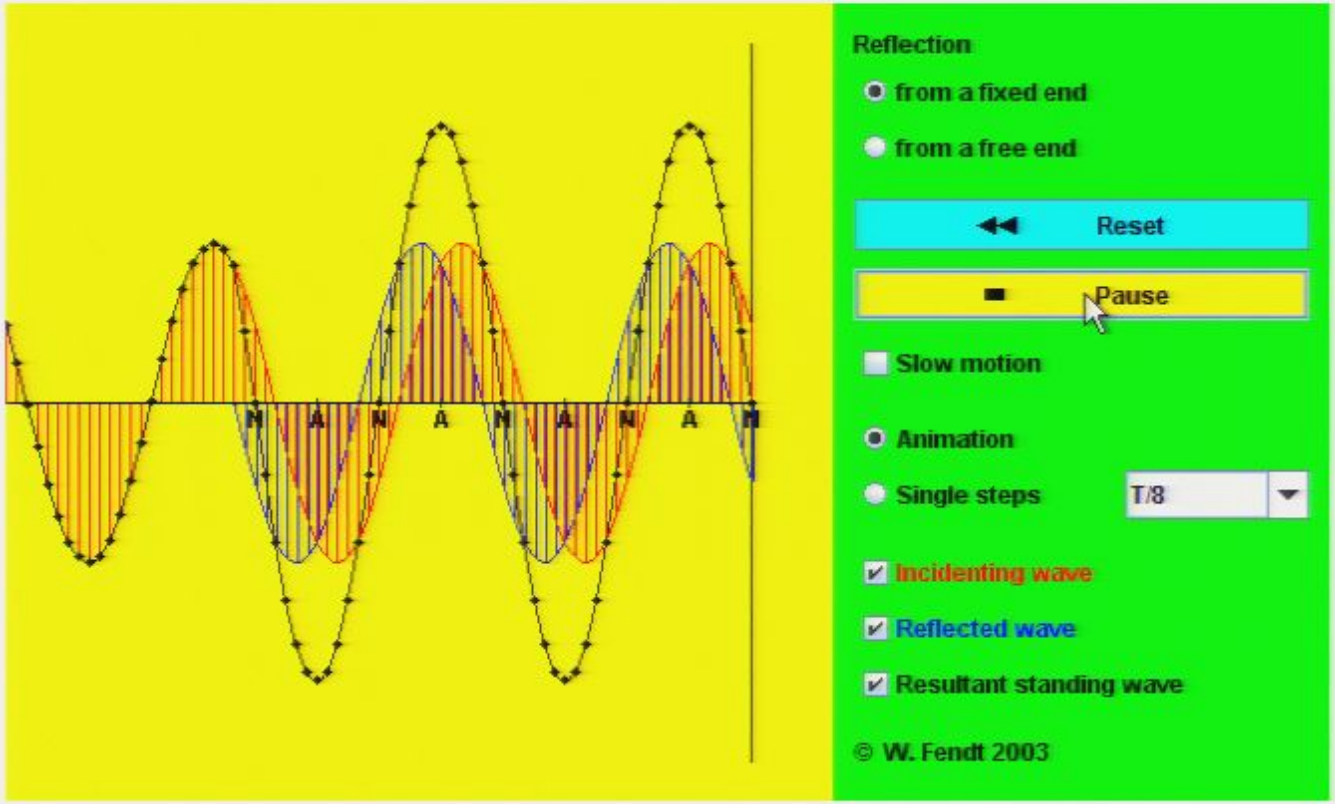

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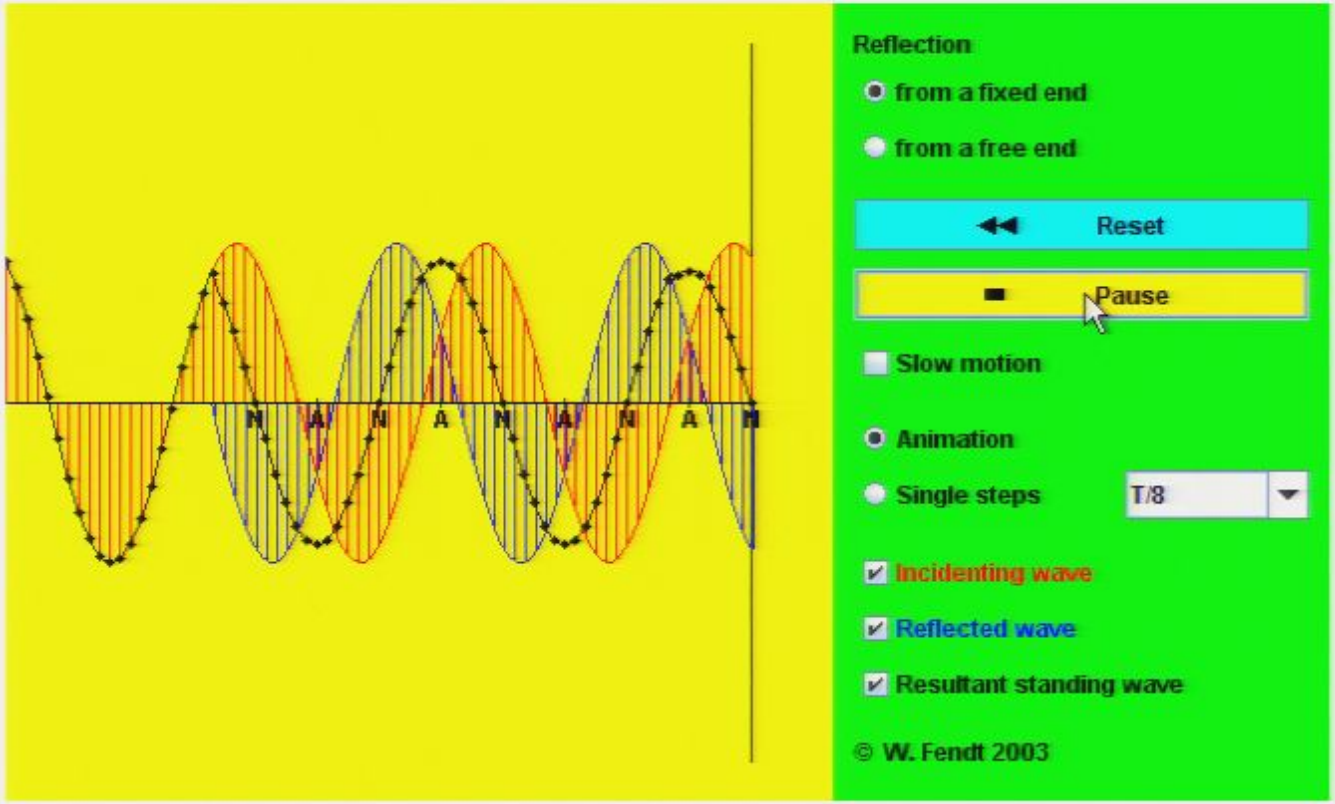

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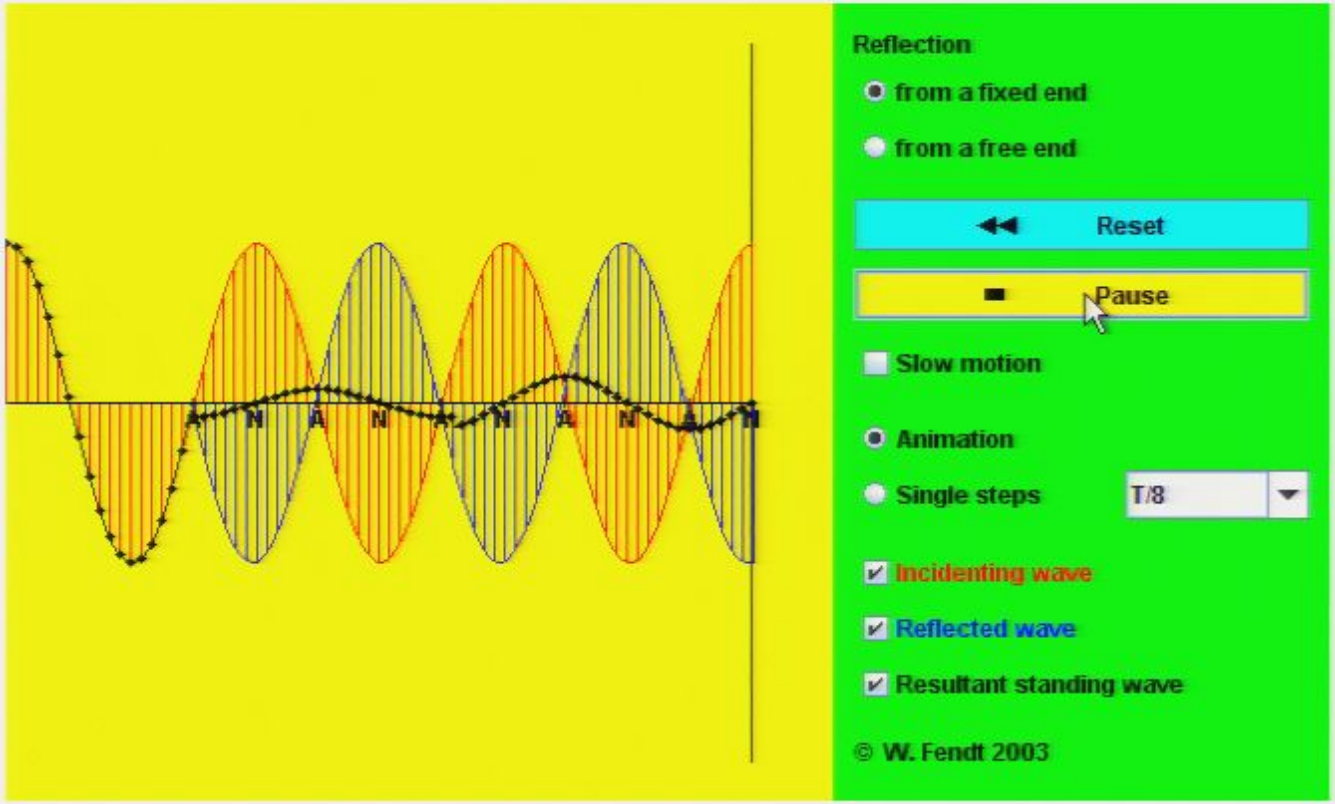

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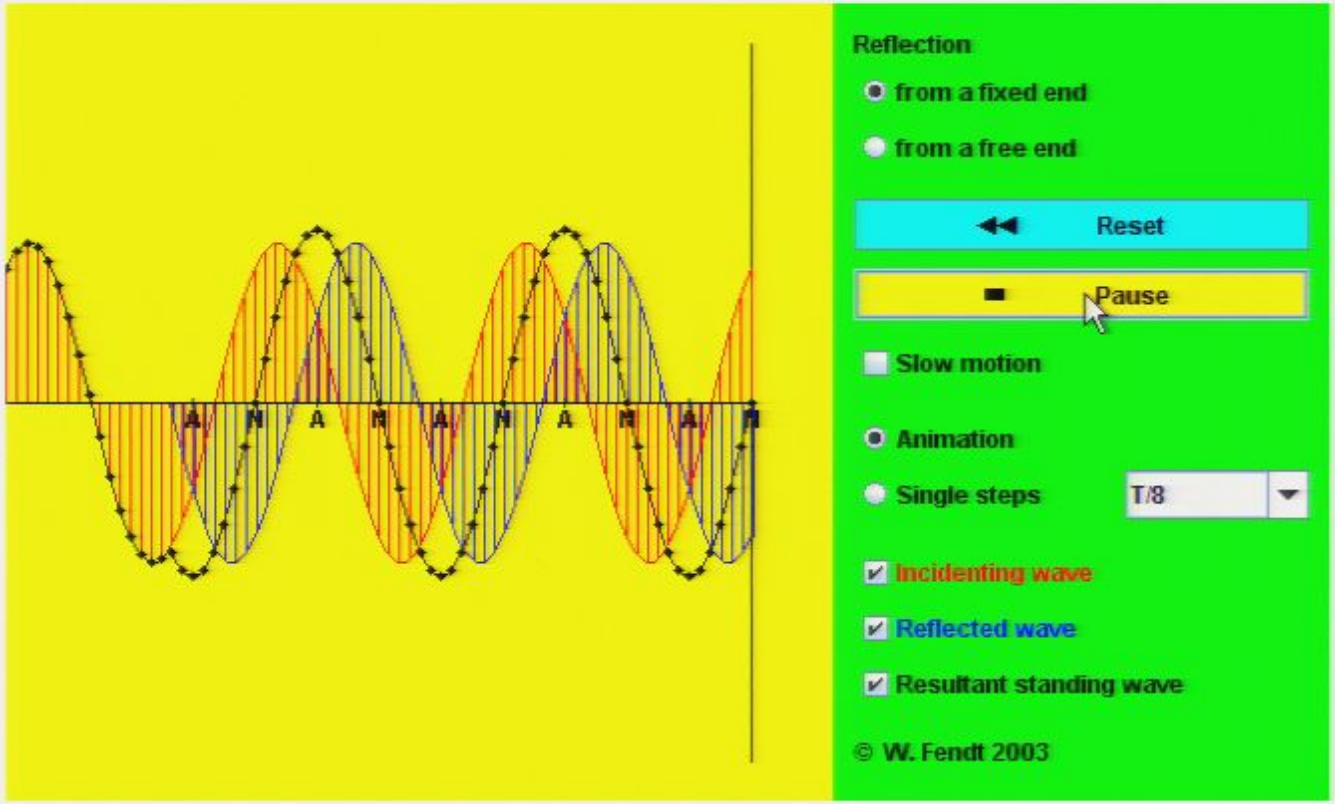

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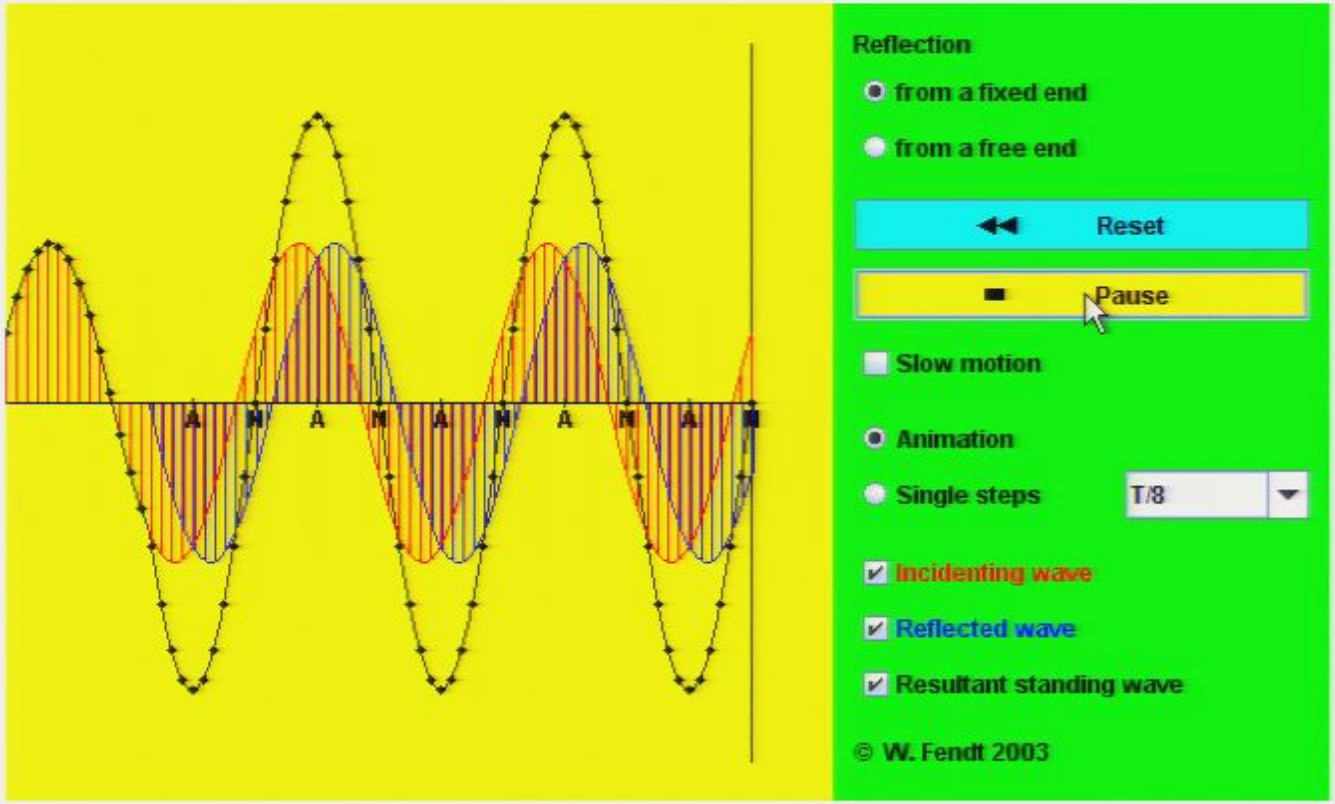

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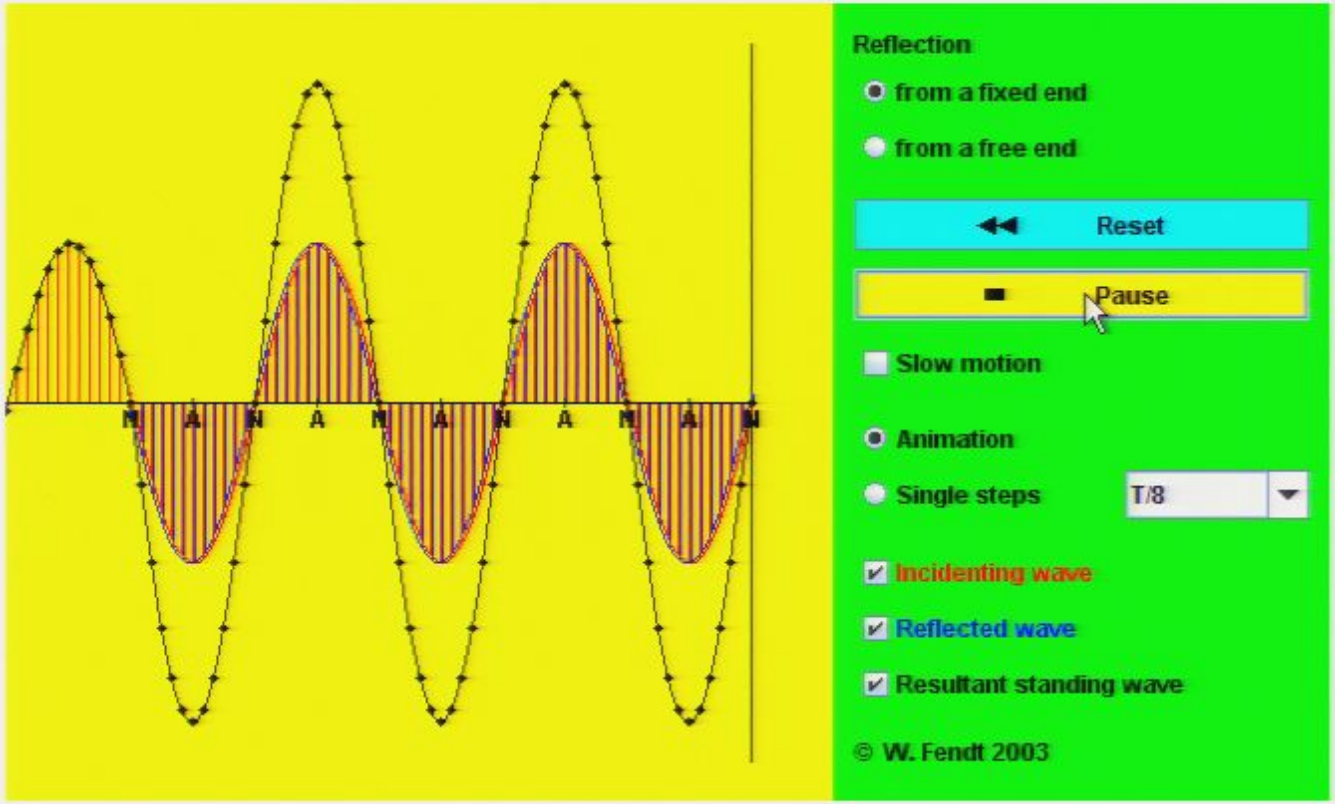

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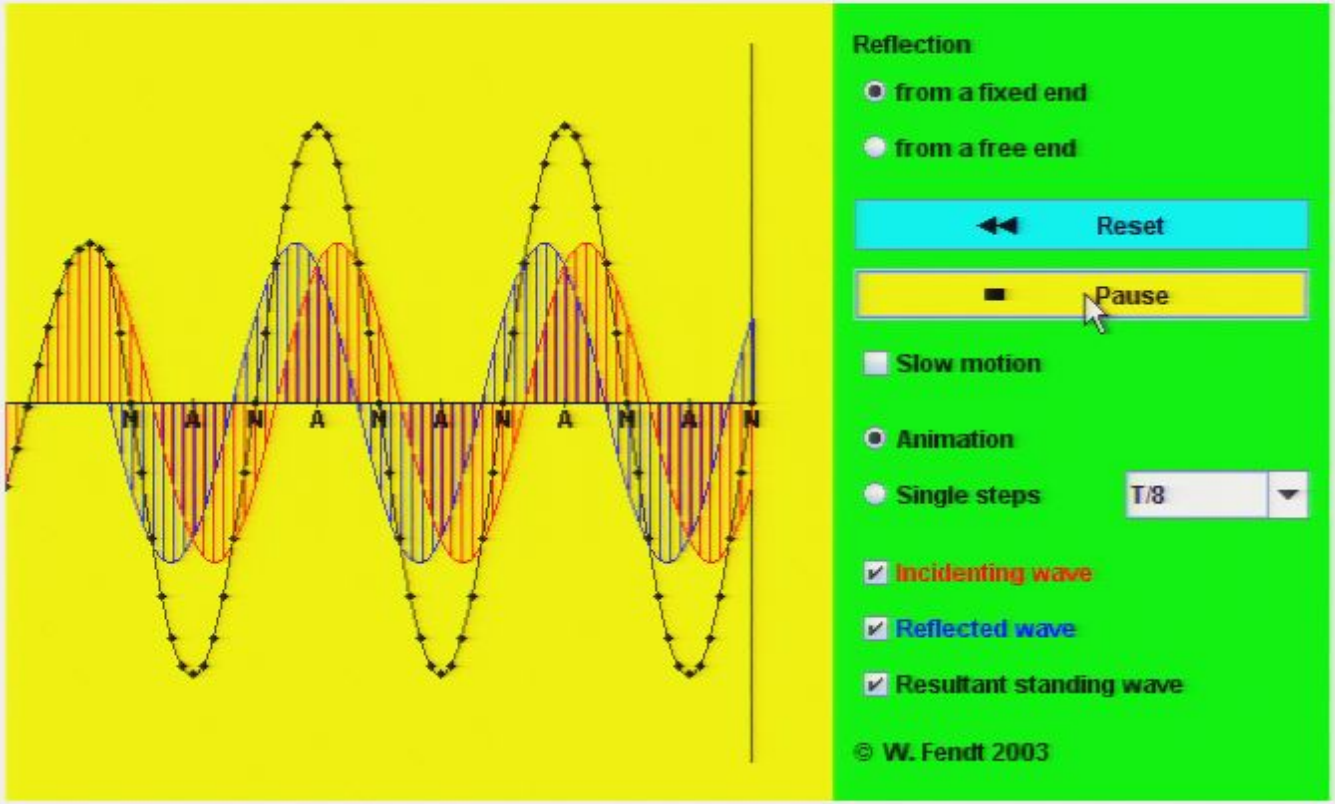

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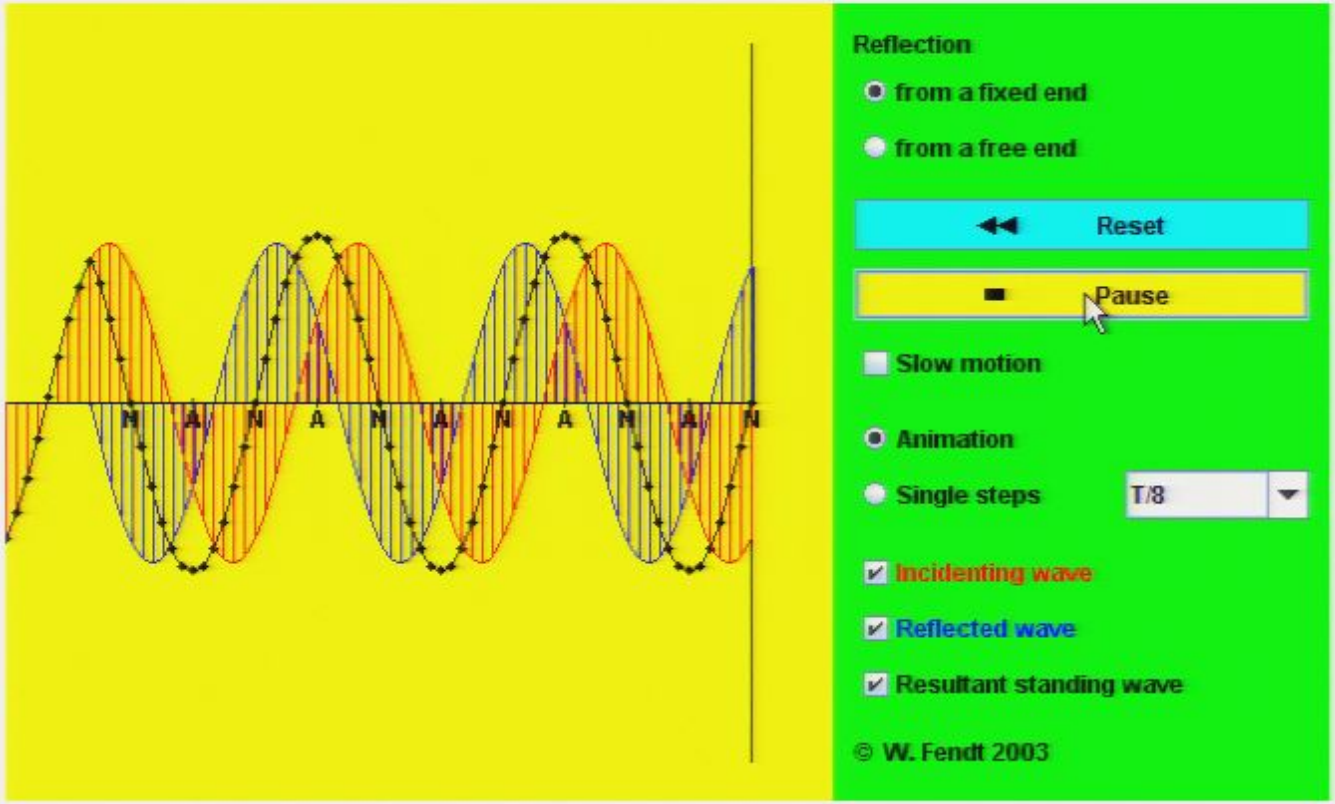

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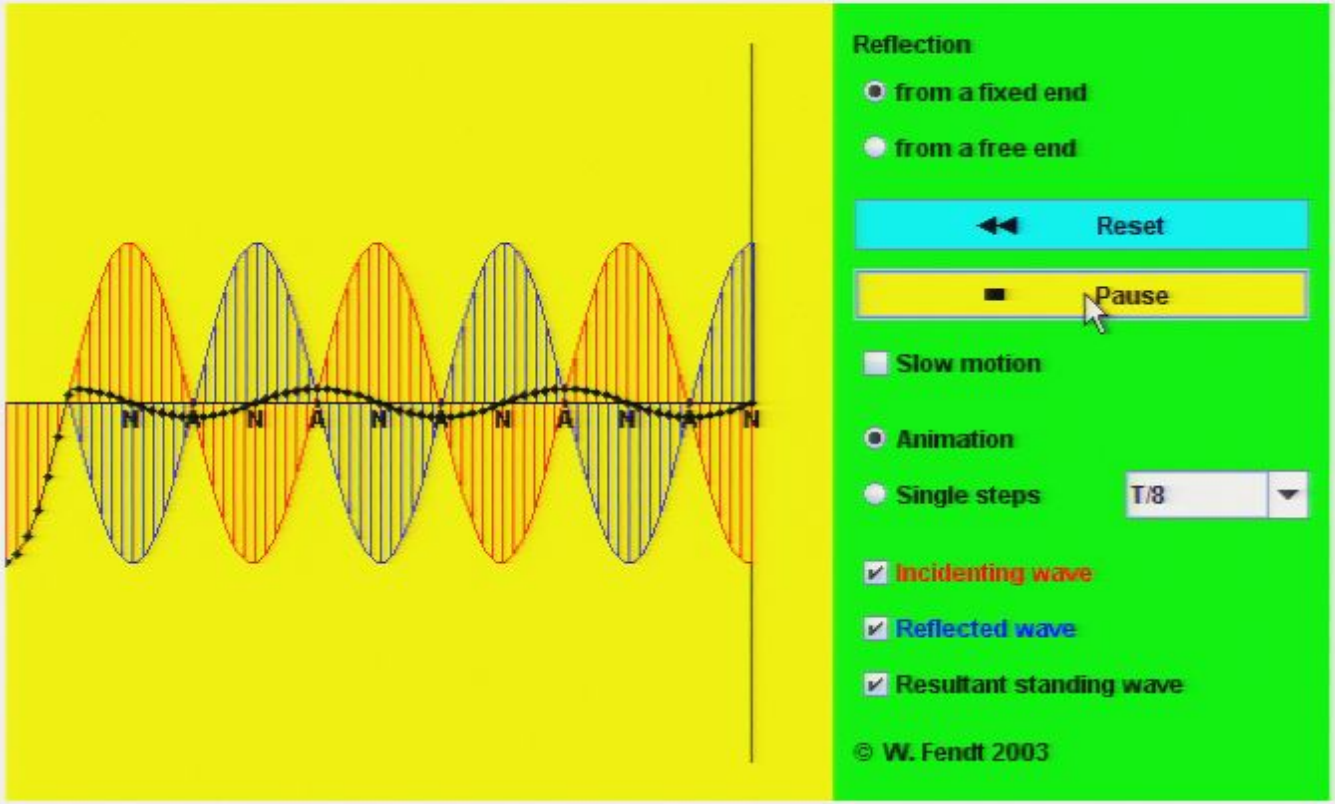

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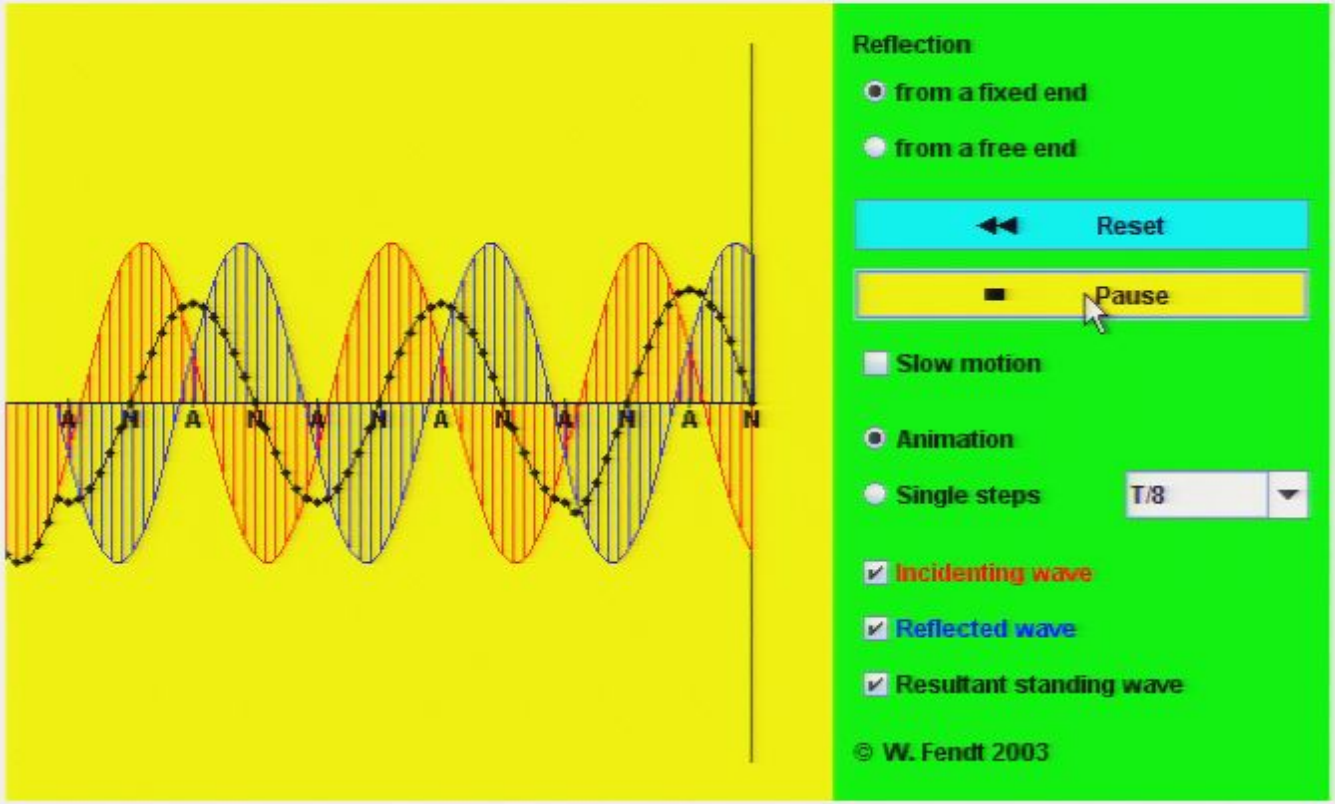

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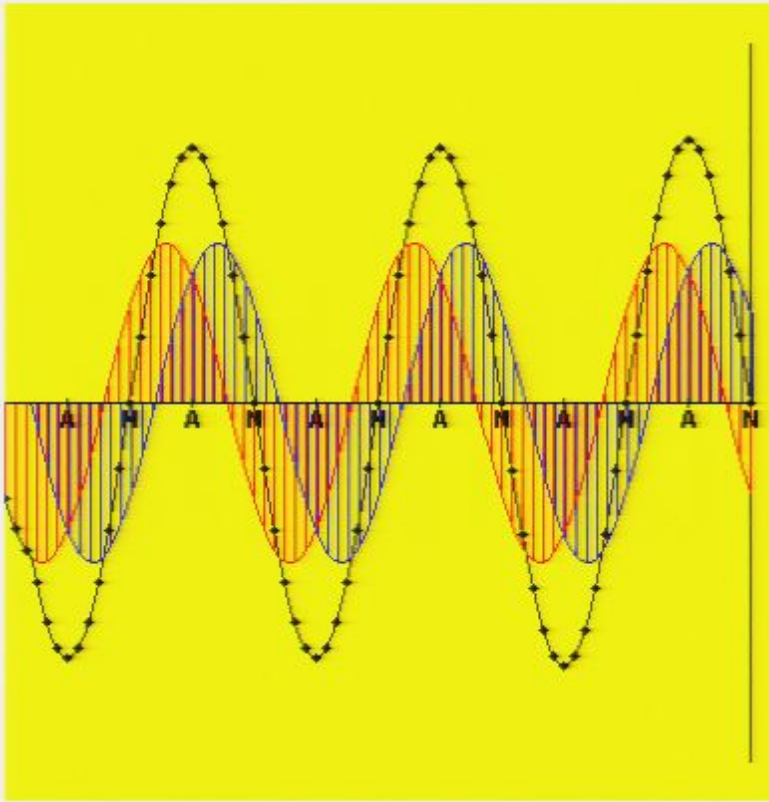

Reflection

- from a fixed end
- from a free end

Reset

Pause

Slow motion

- Animation
- Single steps

T/8

- Incidenting wave
- Reflected wave
- Resultant standing wave

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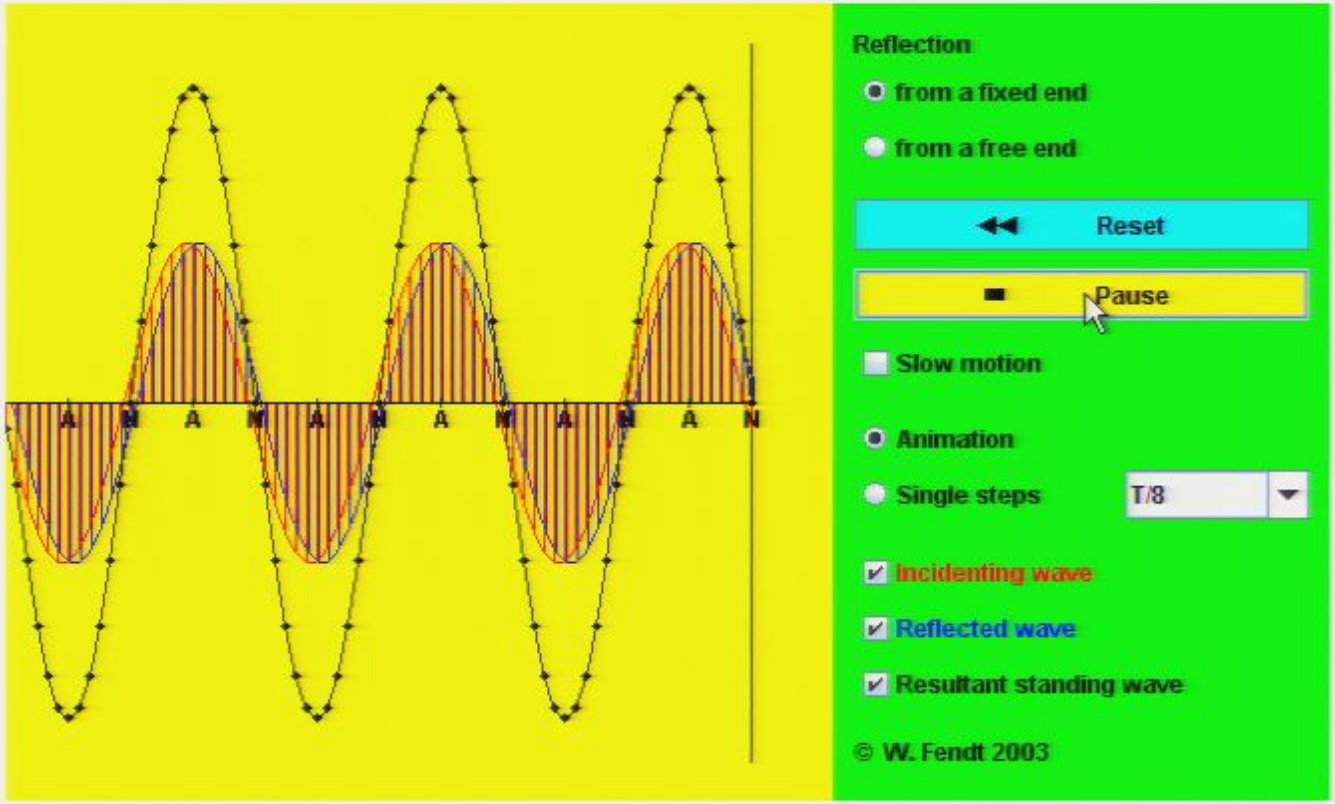

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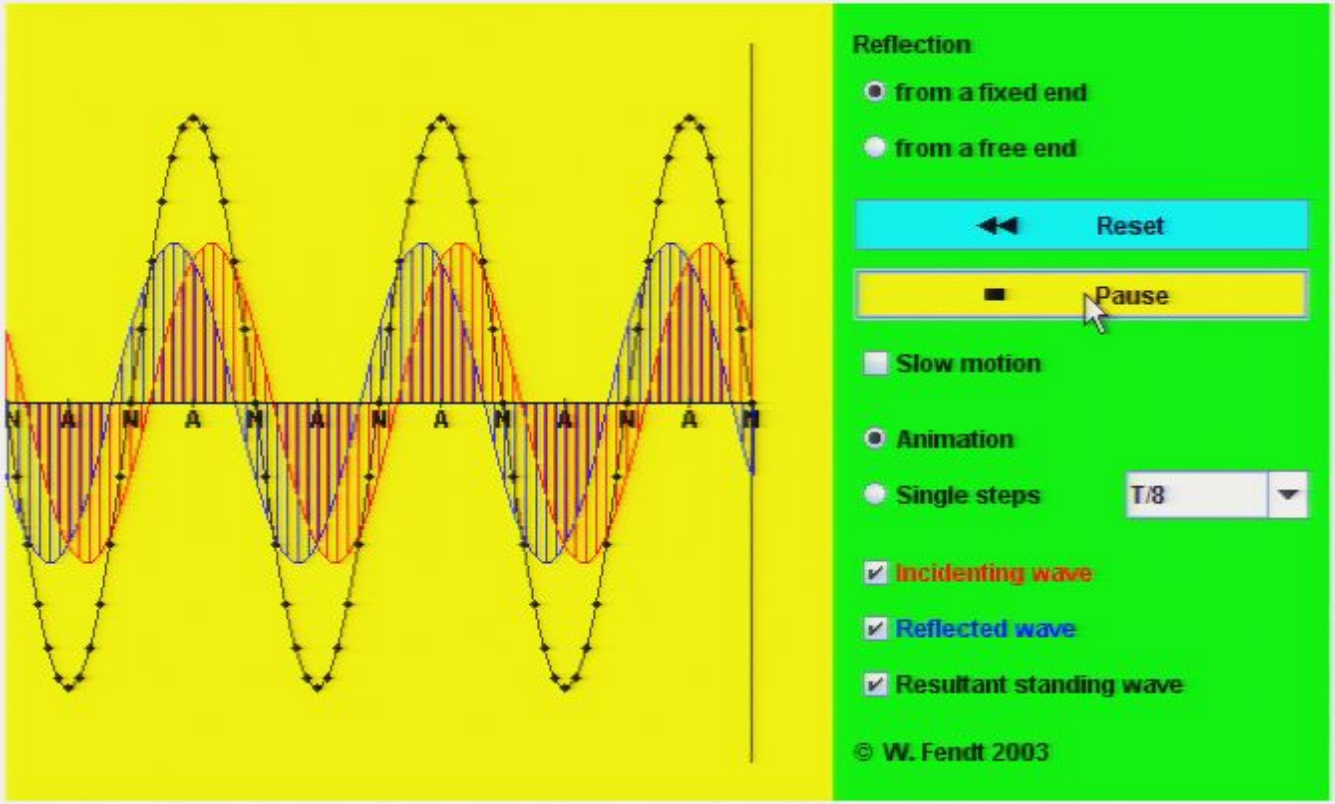

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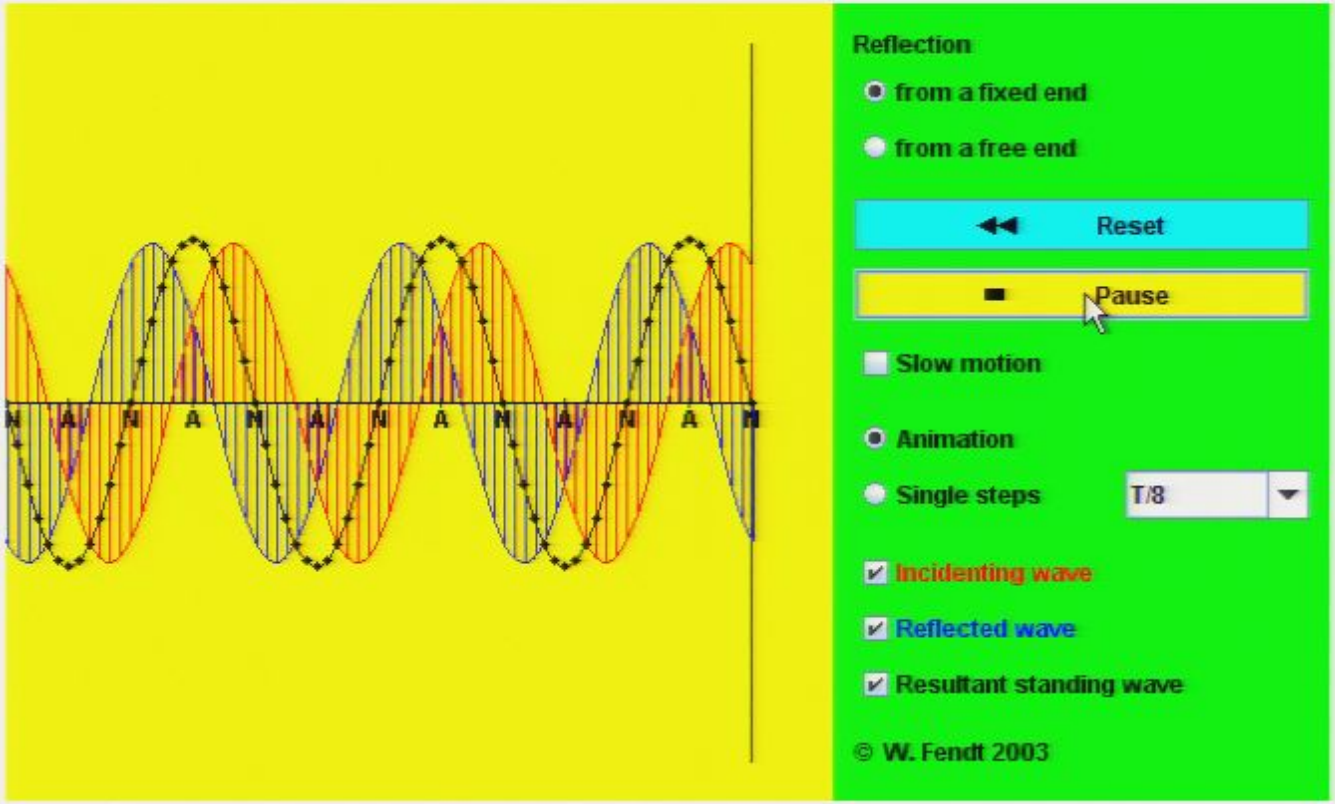

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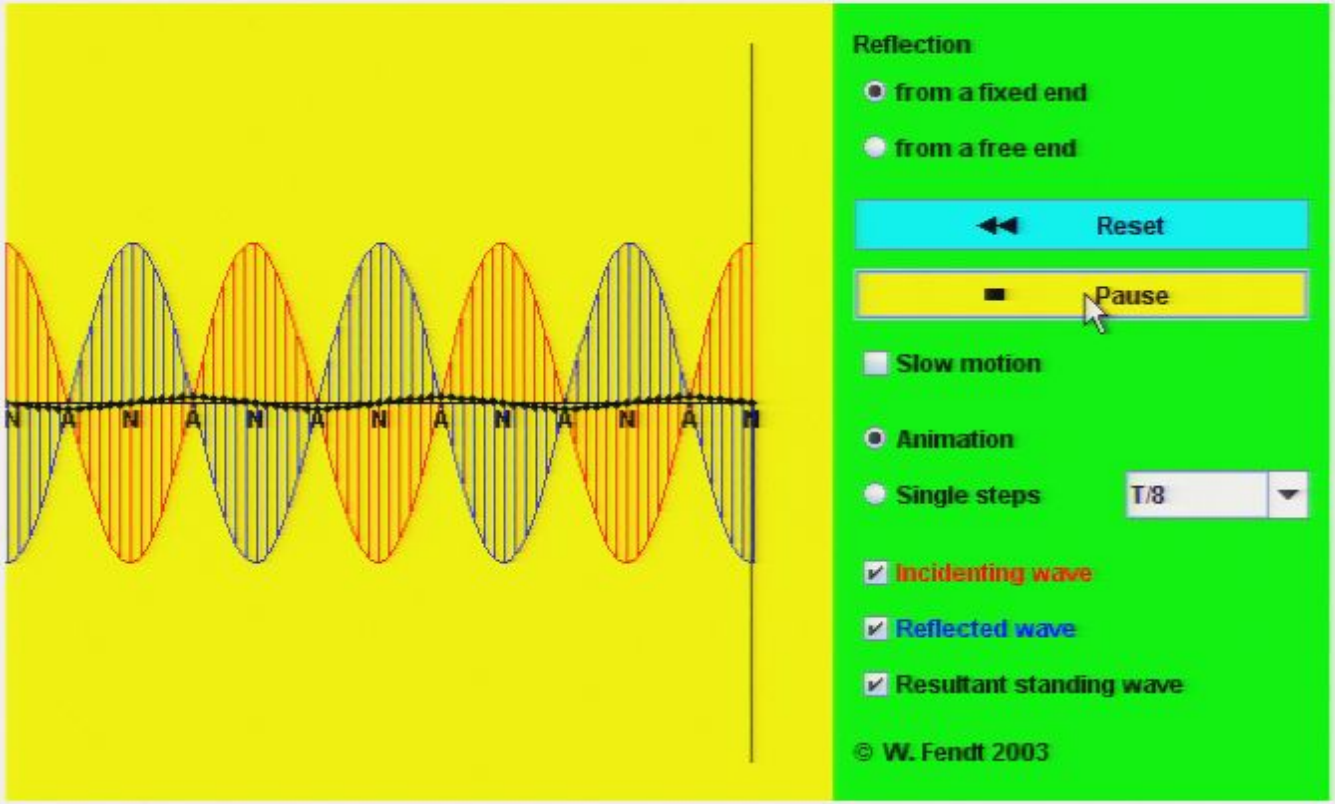

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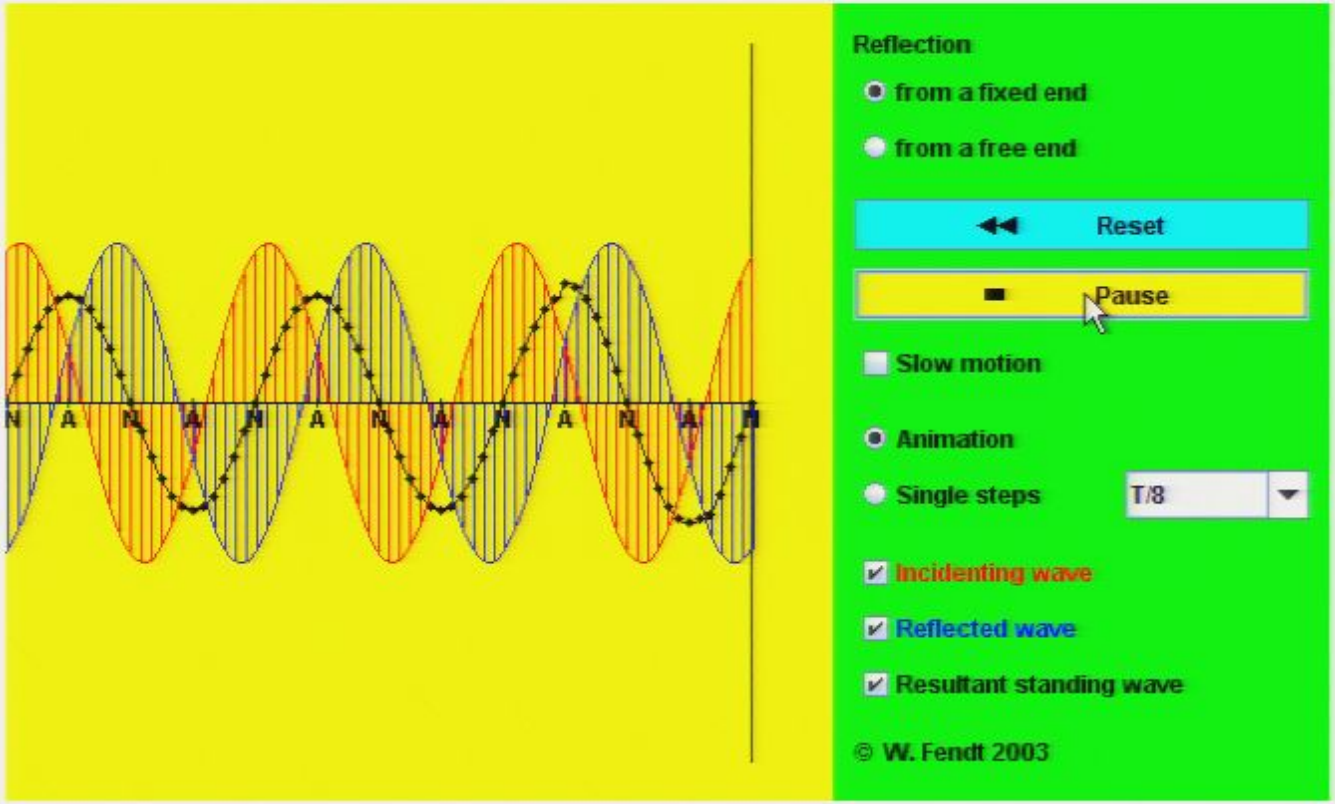

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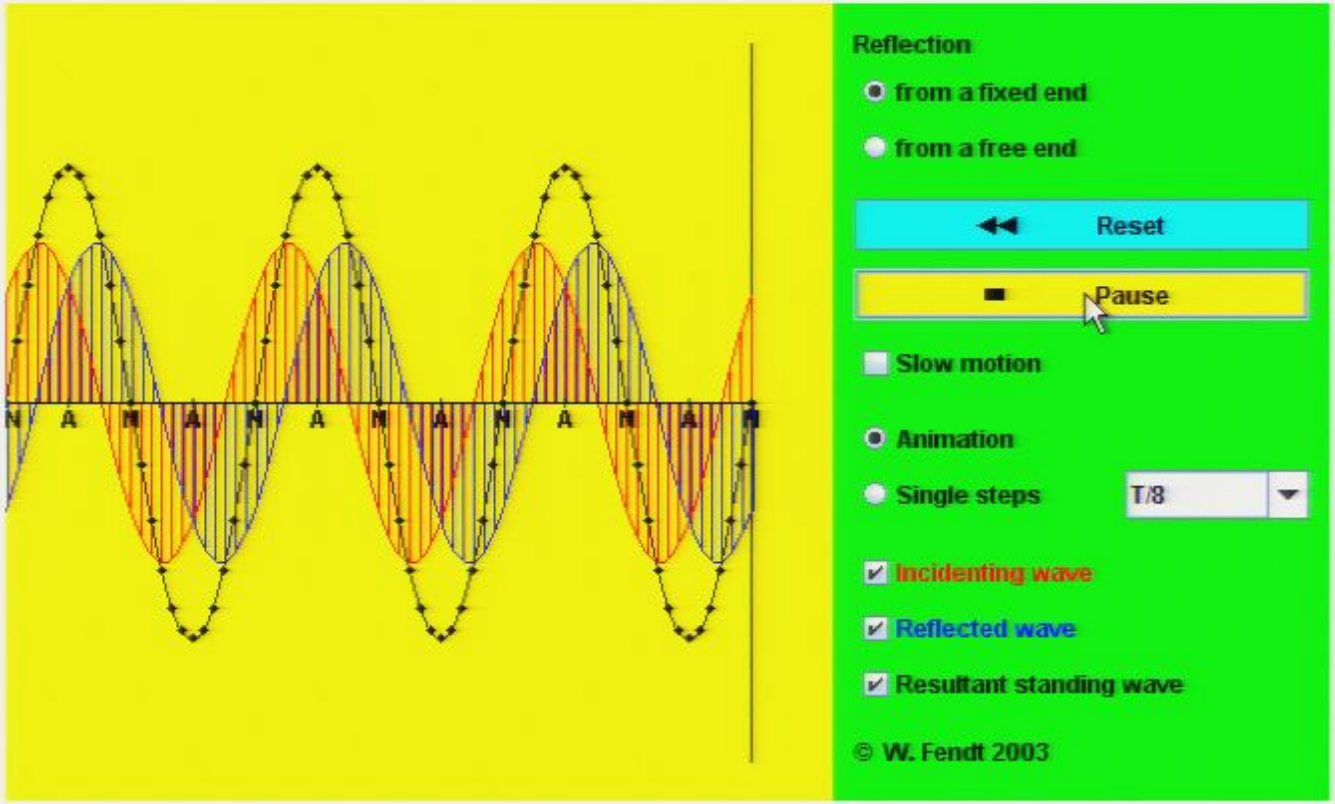

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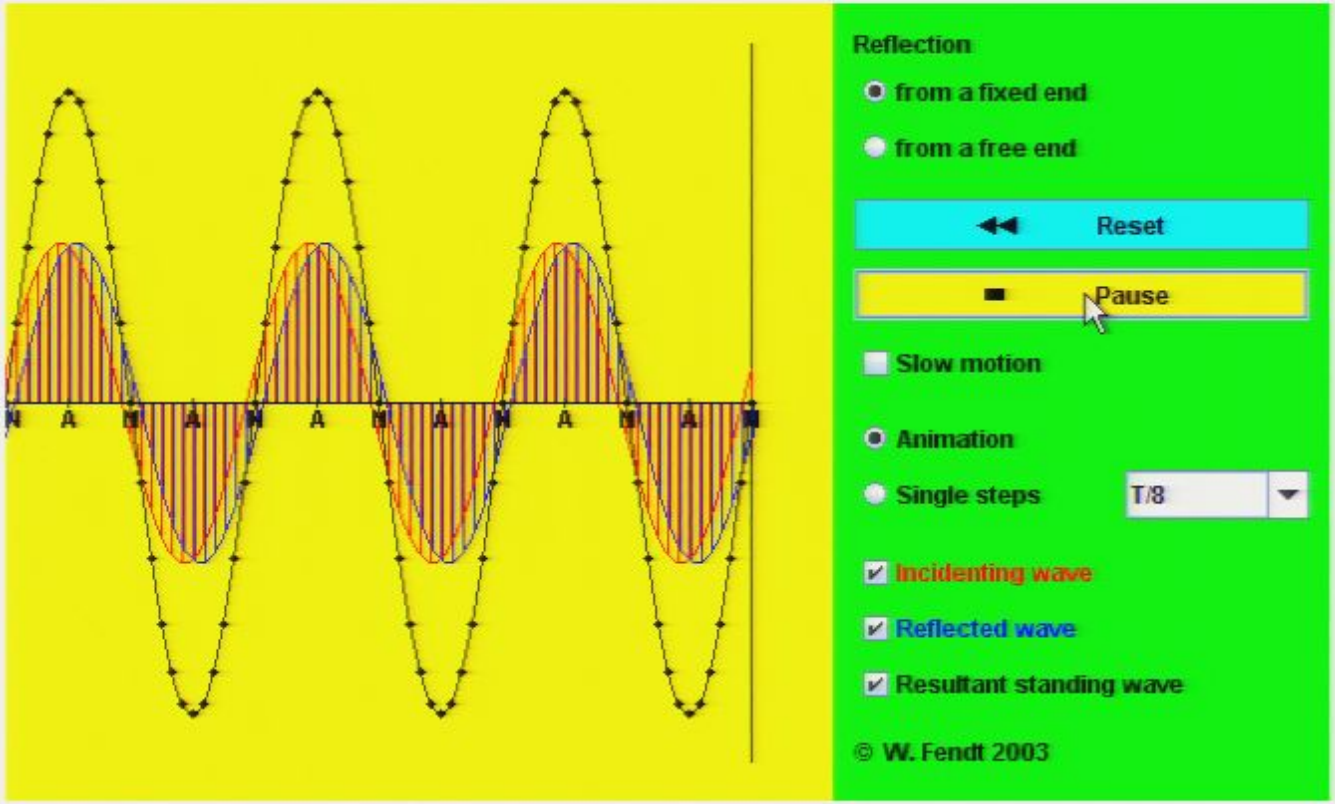

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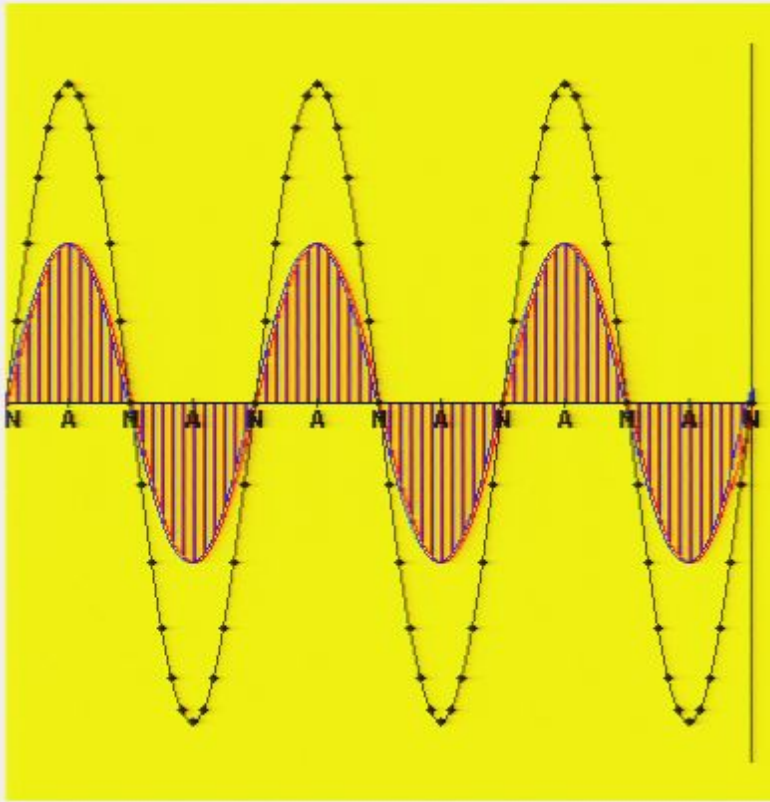

Reflection

- from a fixed end
- from a free end

Reset

Pause

Slow motion

- Animation
- Single steps T/8

- Incidenting wave
- Reflected wave
- Resultant standing wave

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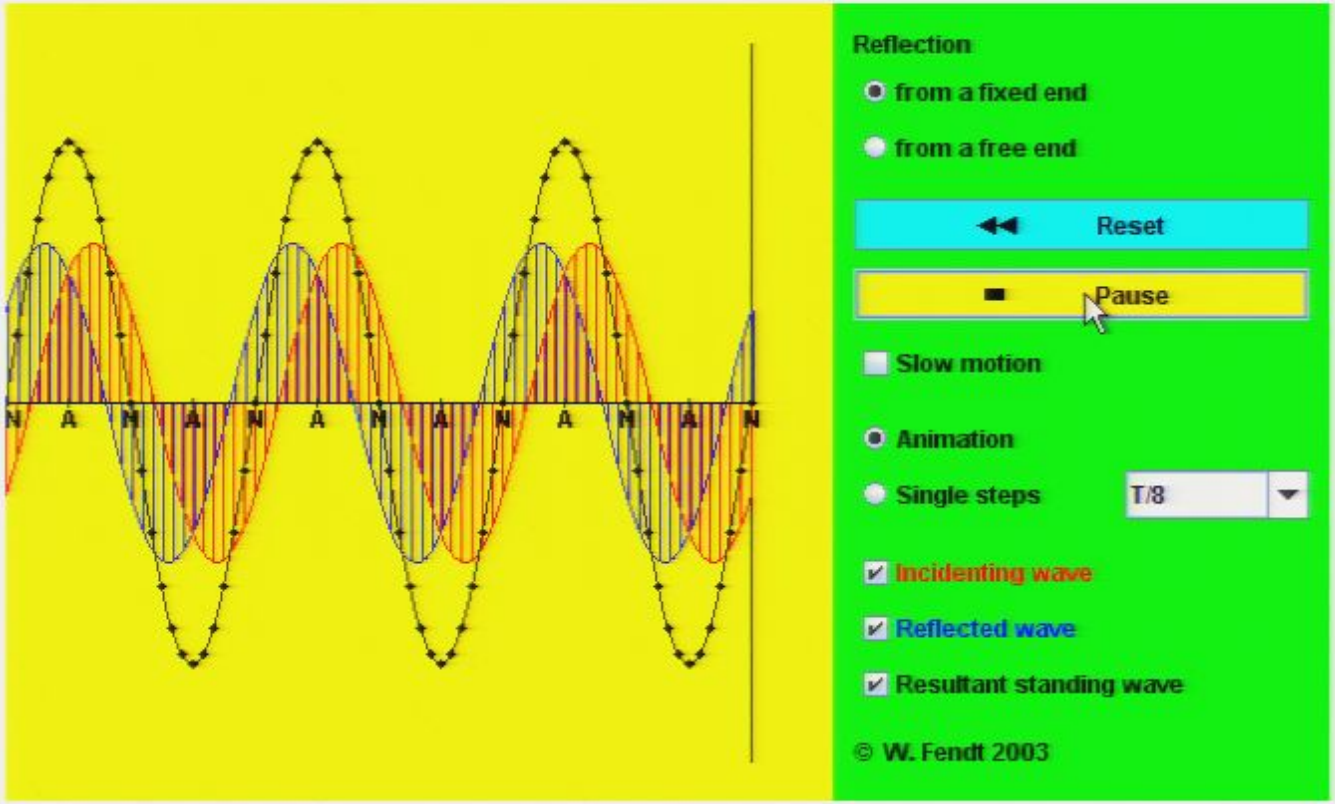

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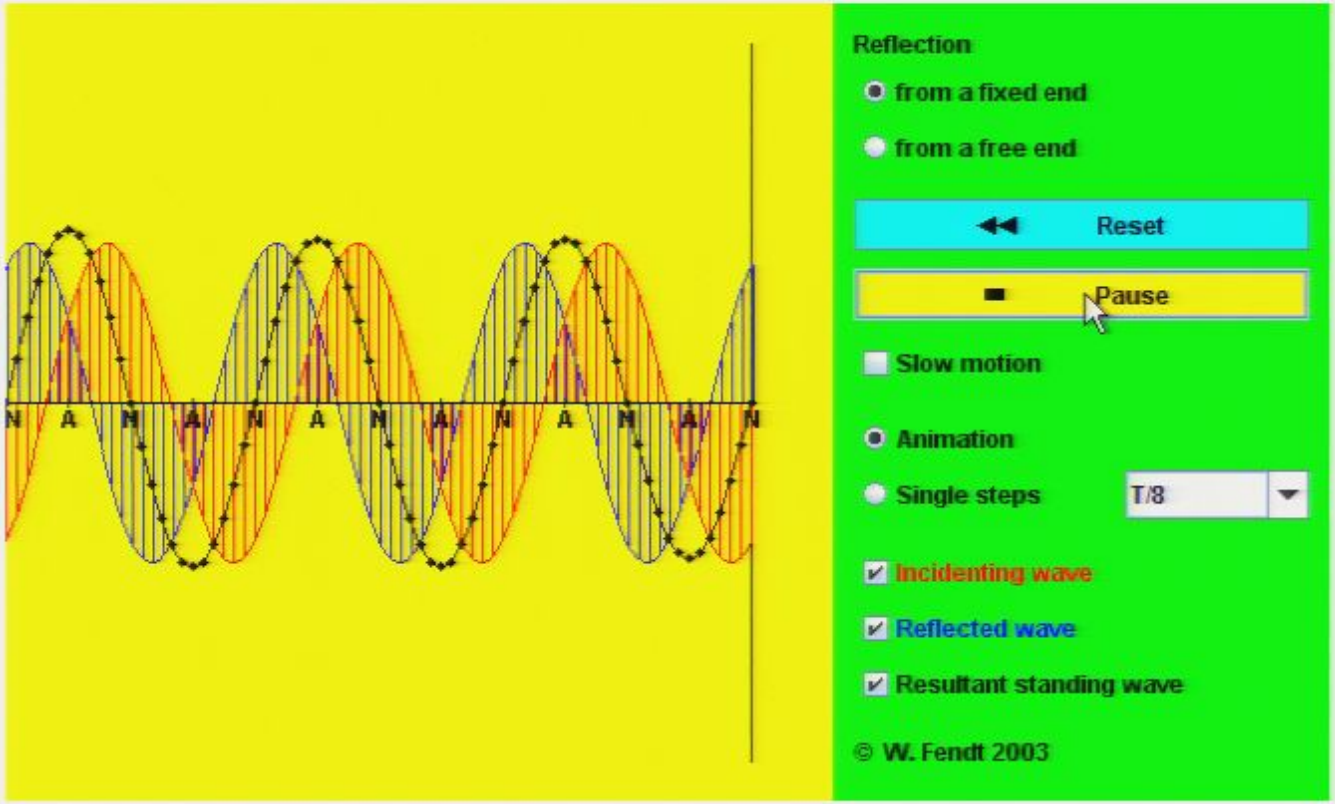

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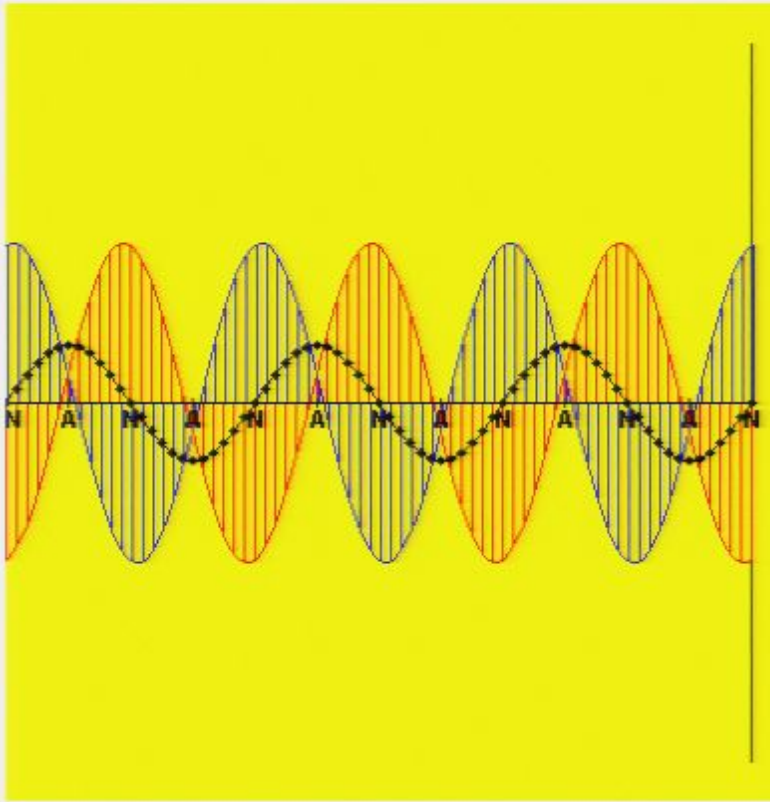

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Reflected wave

Resultant standing wave

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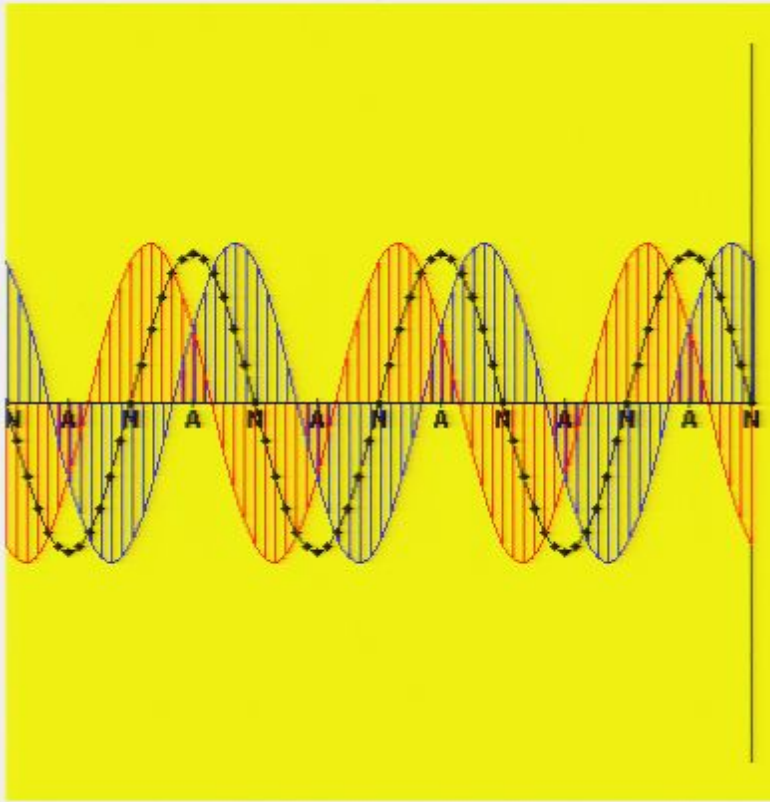

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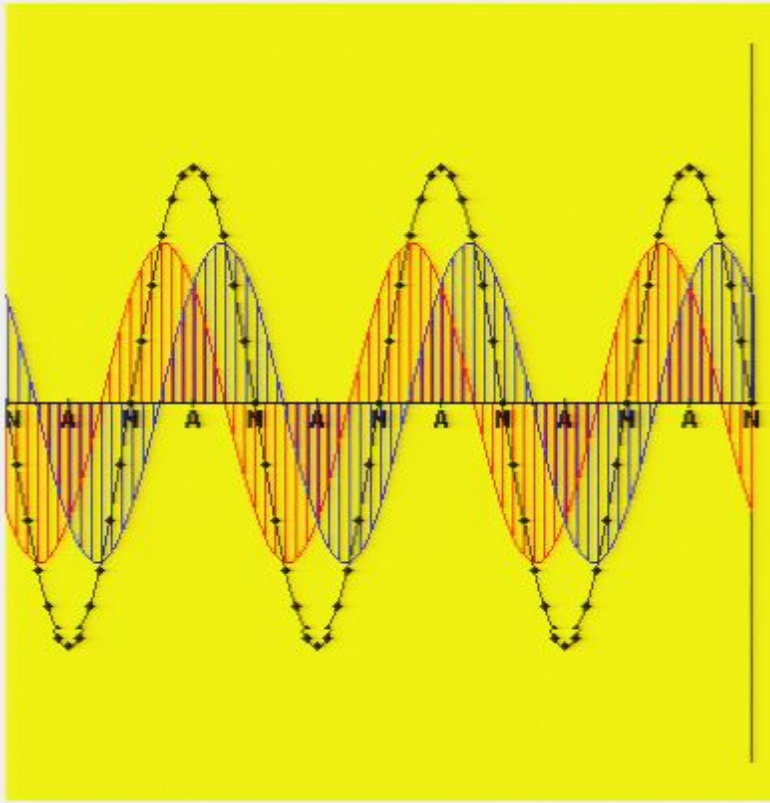

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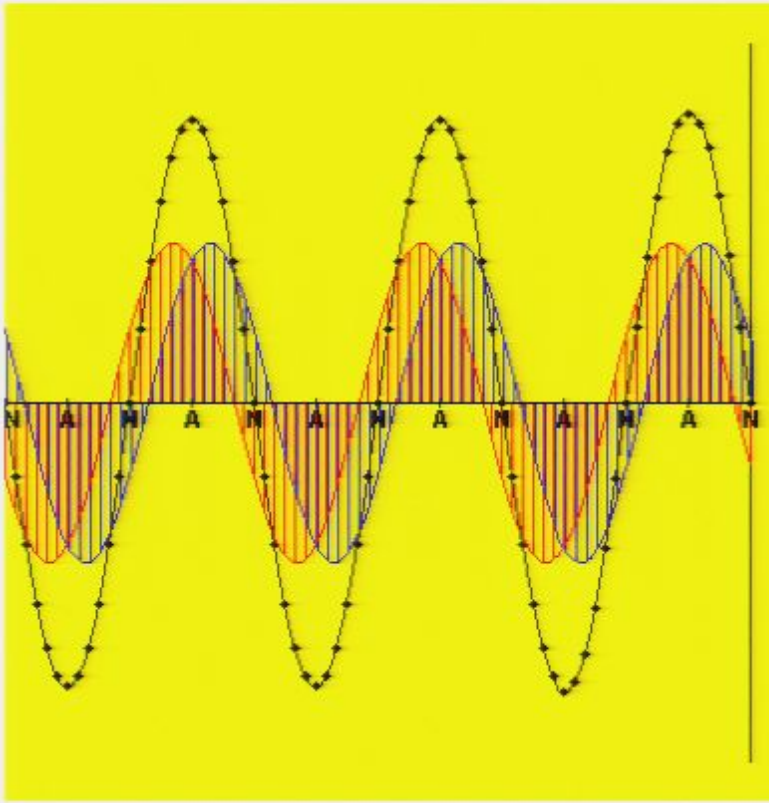

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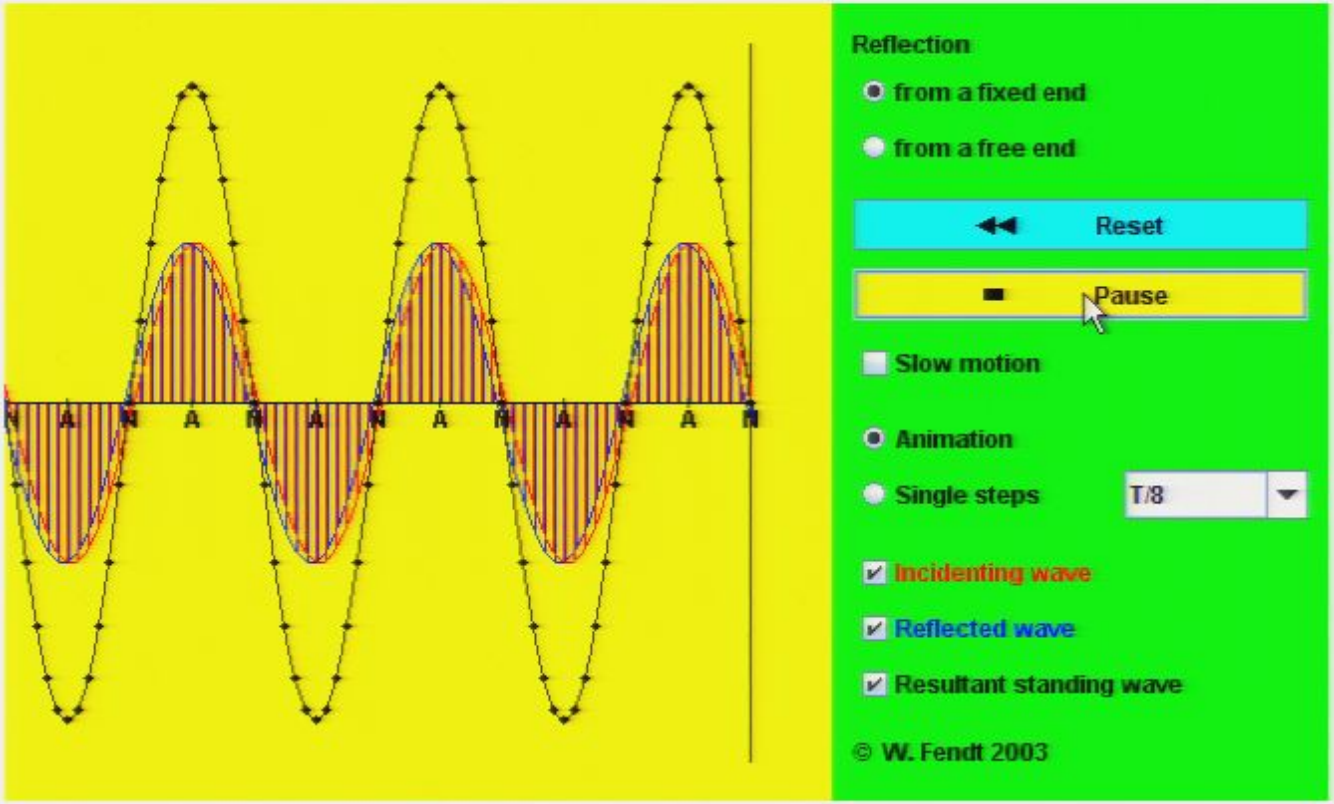

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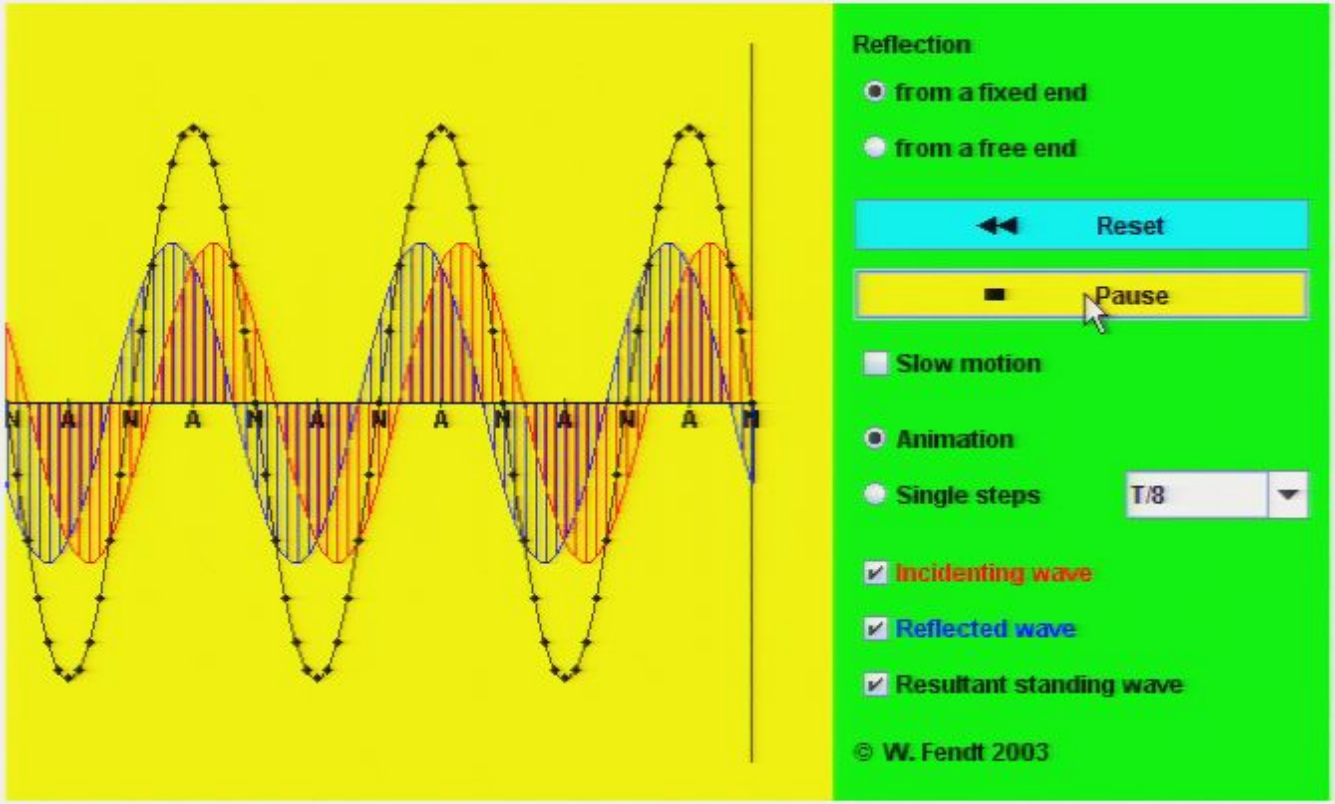

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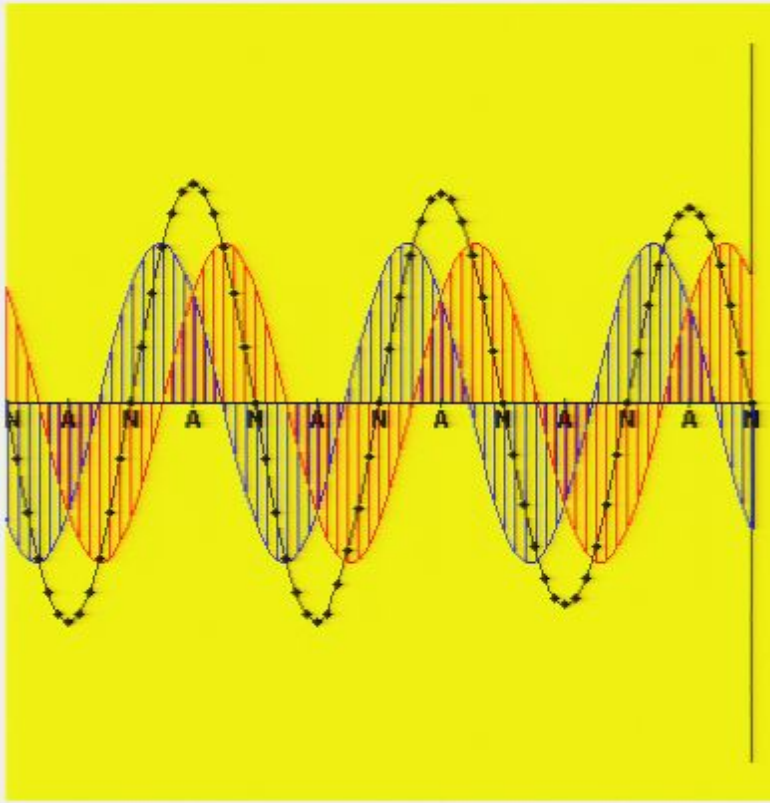

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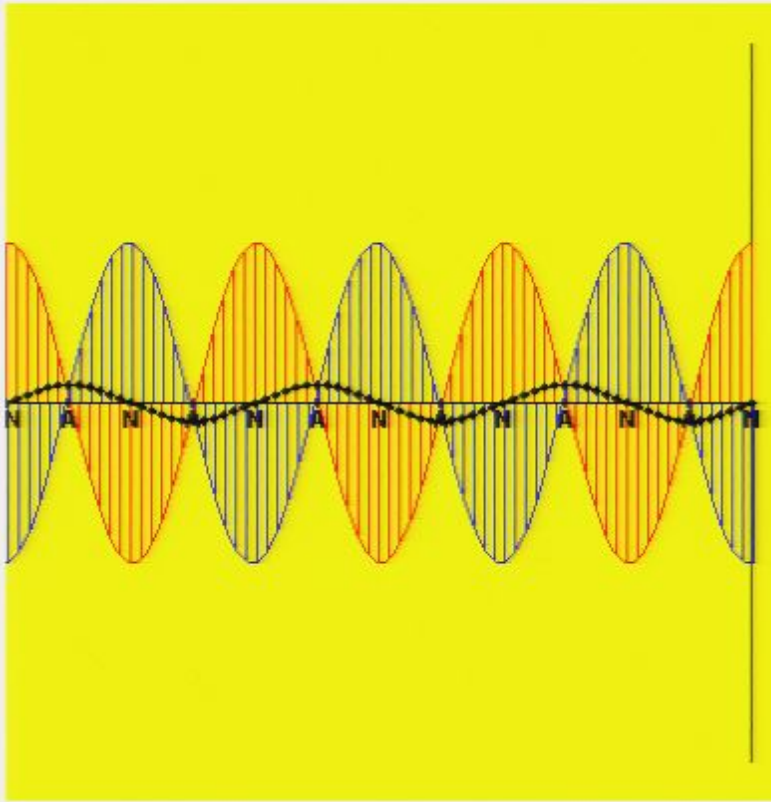

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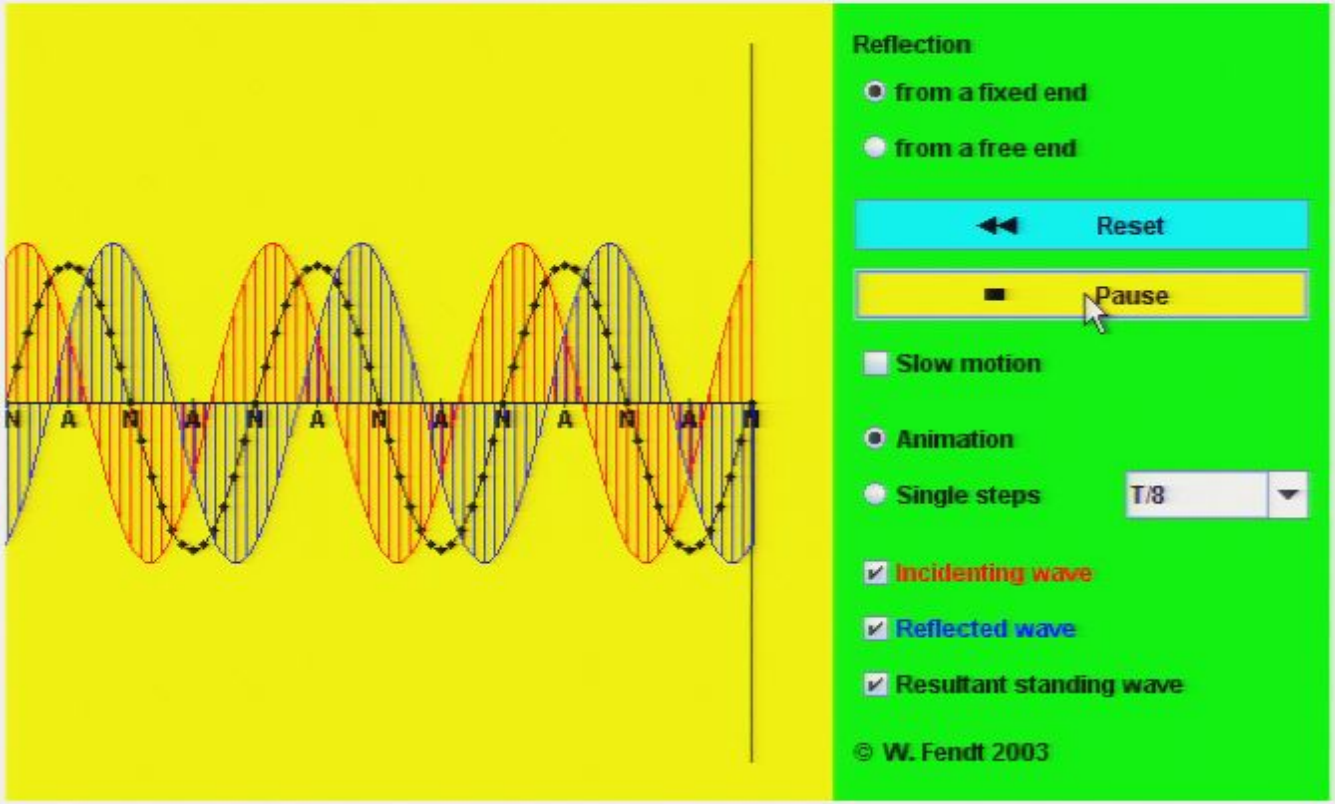

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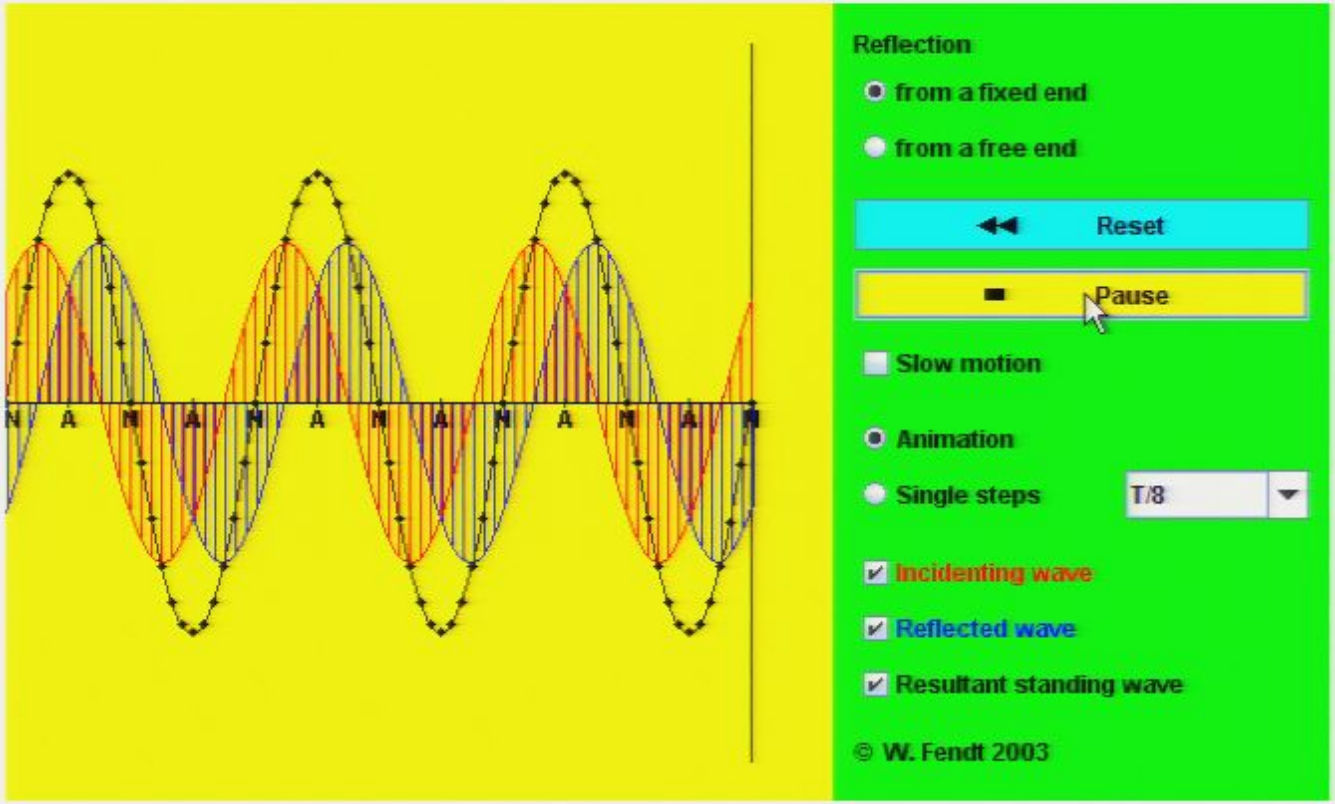

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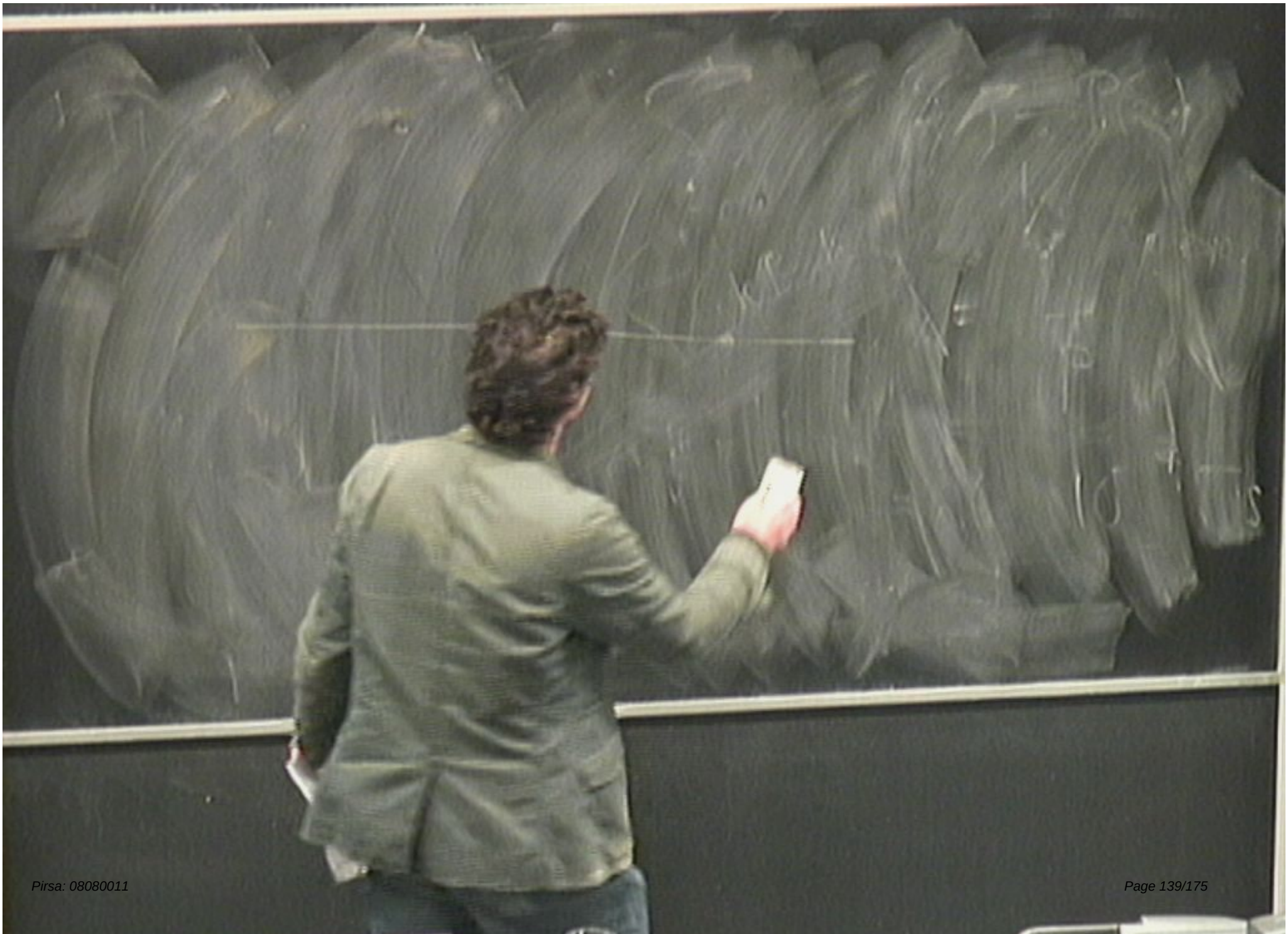
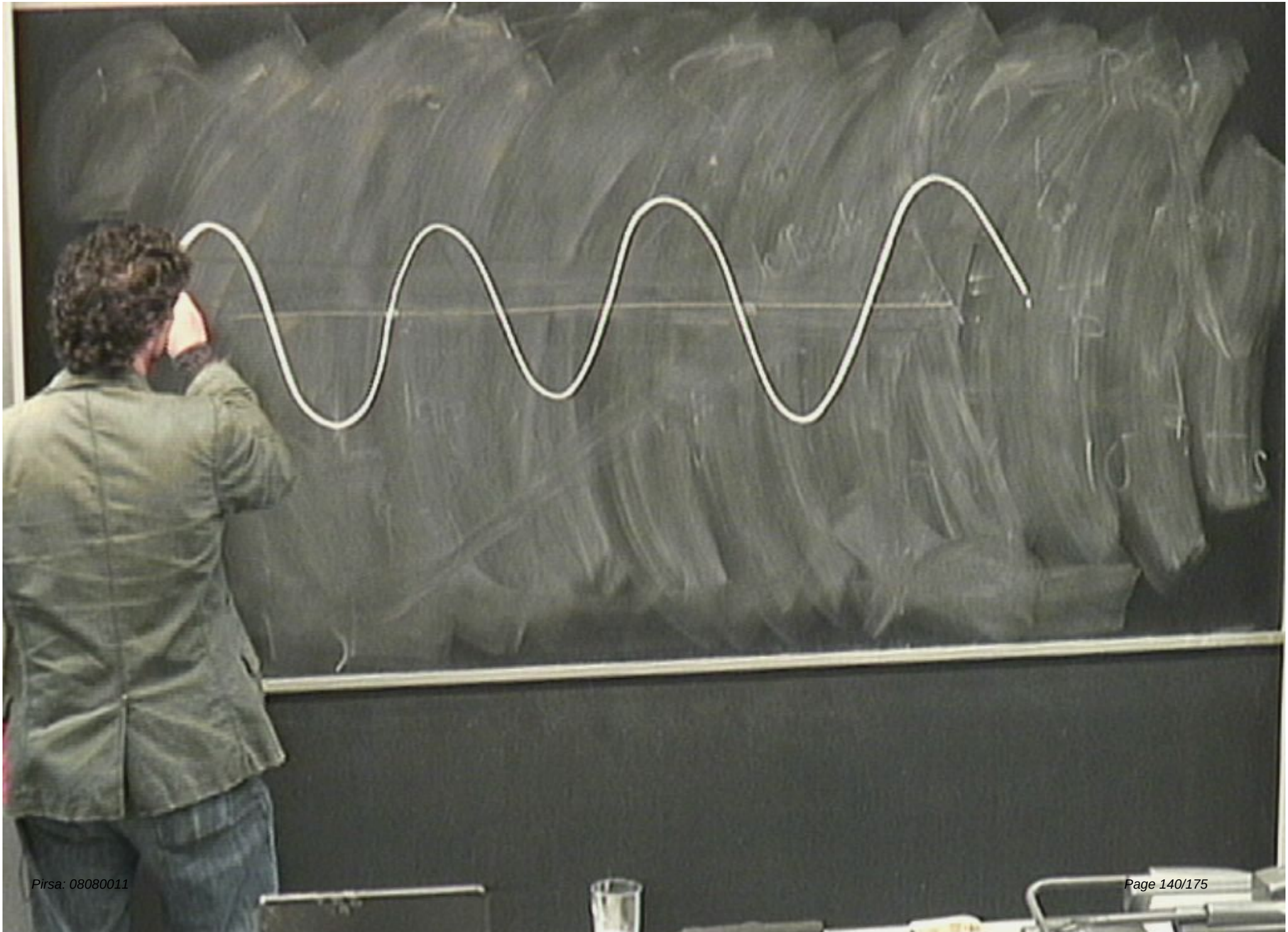
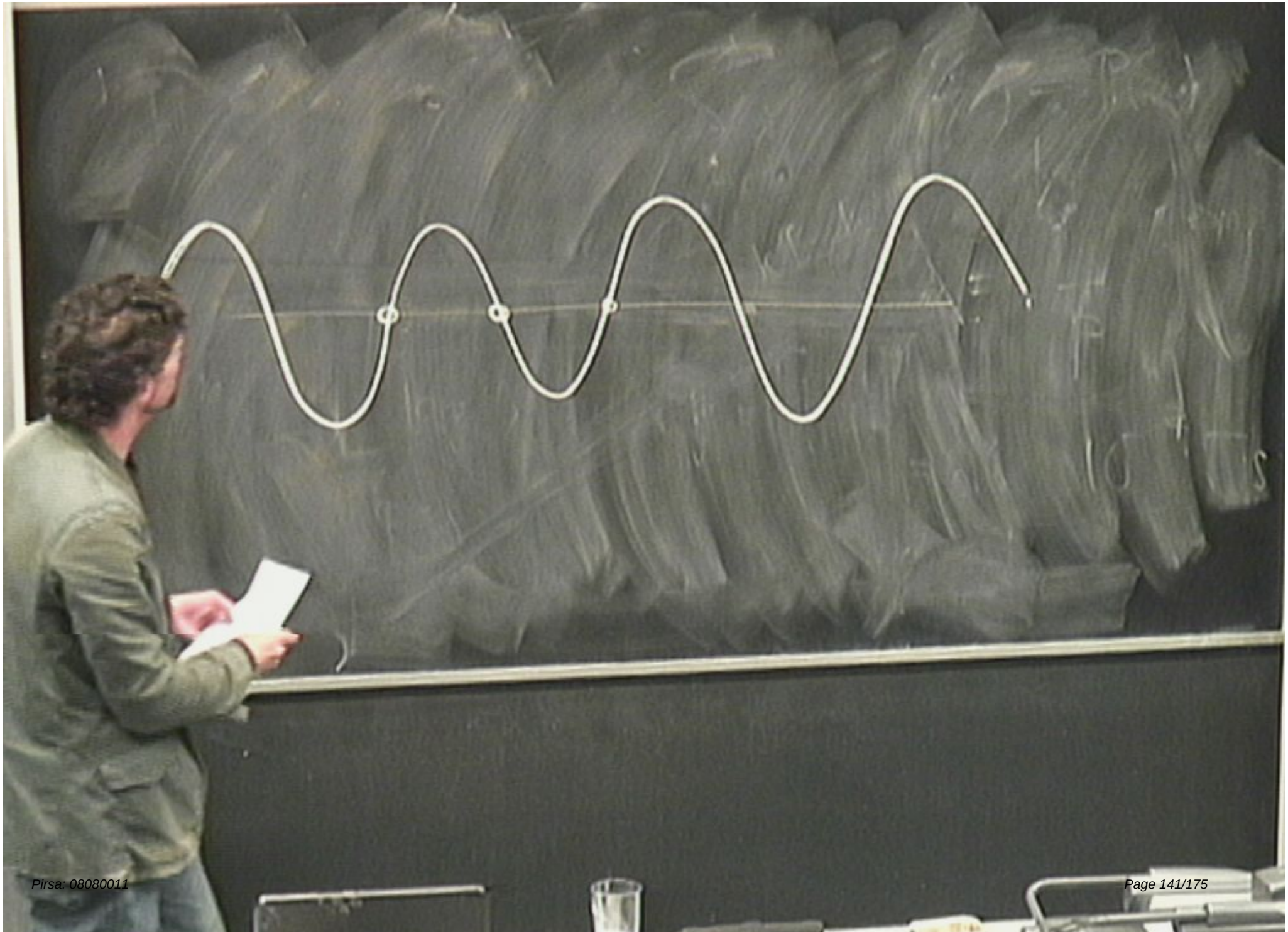
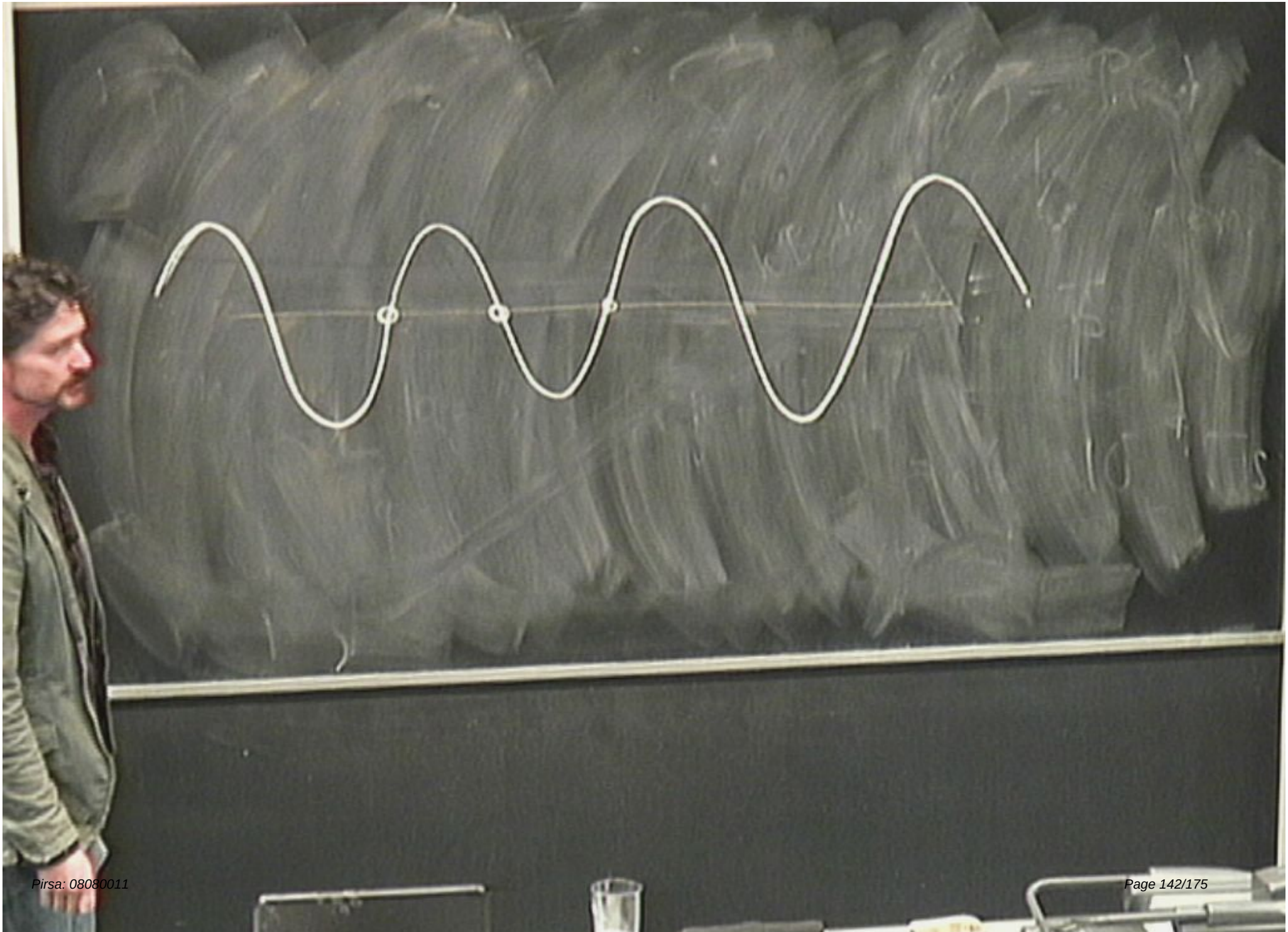
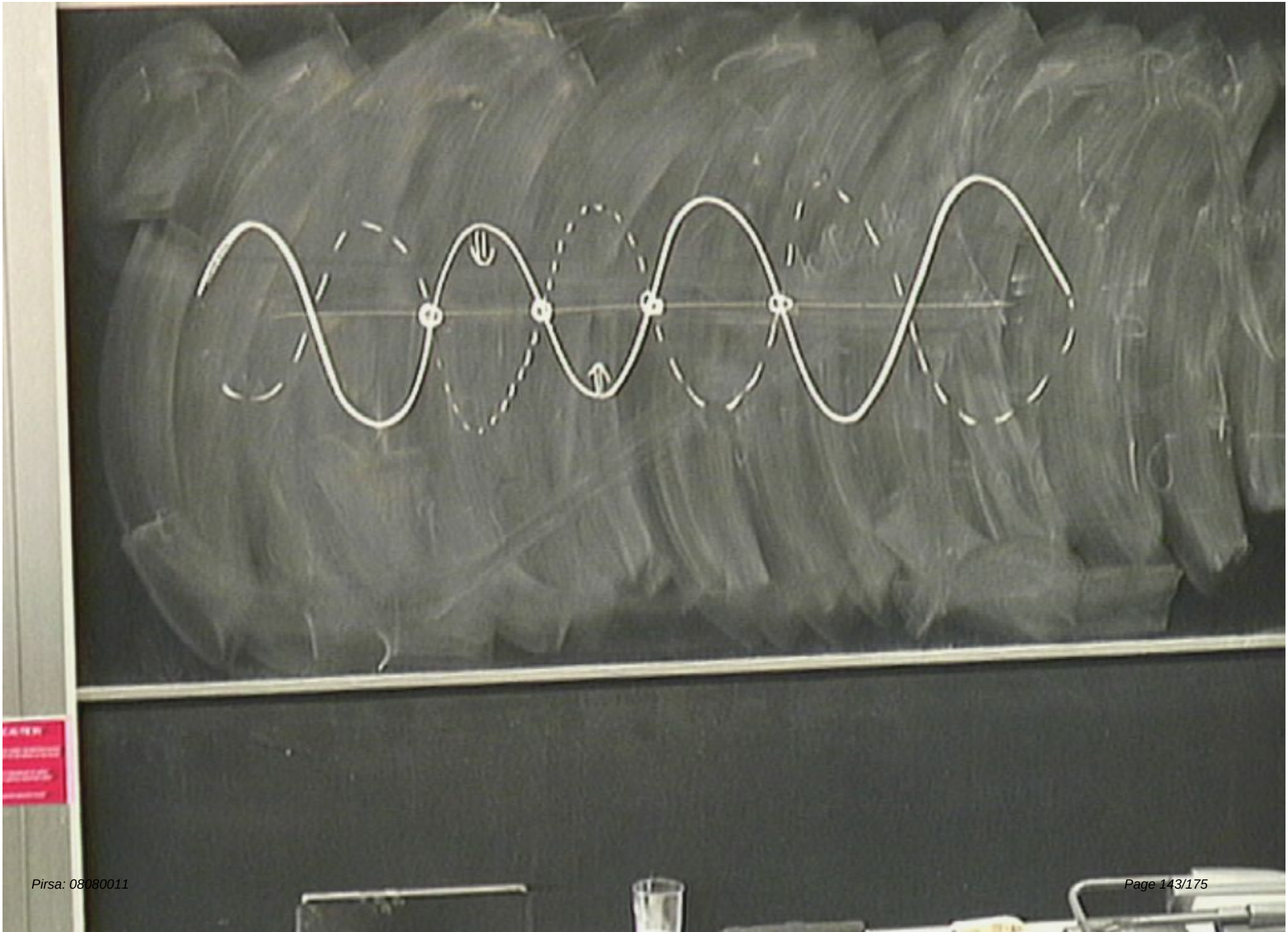
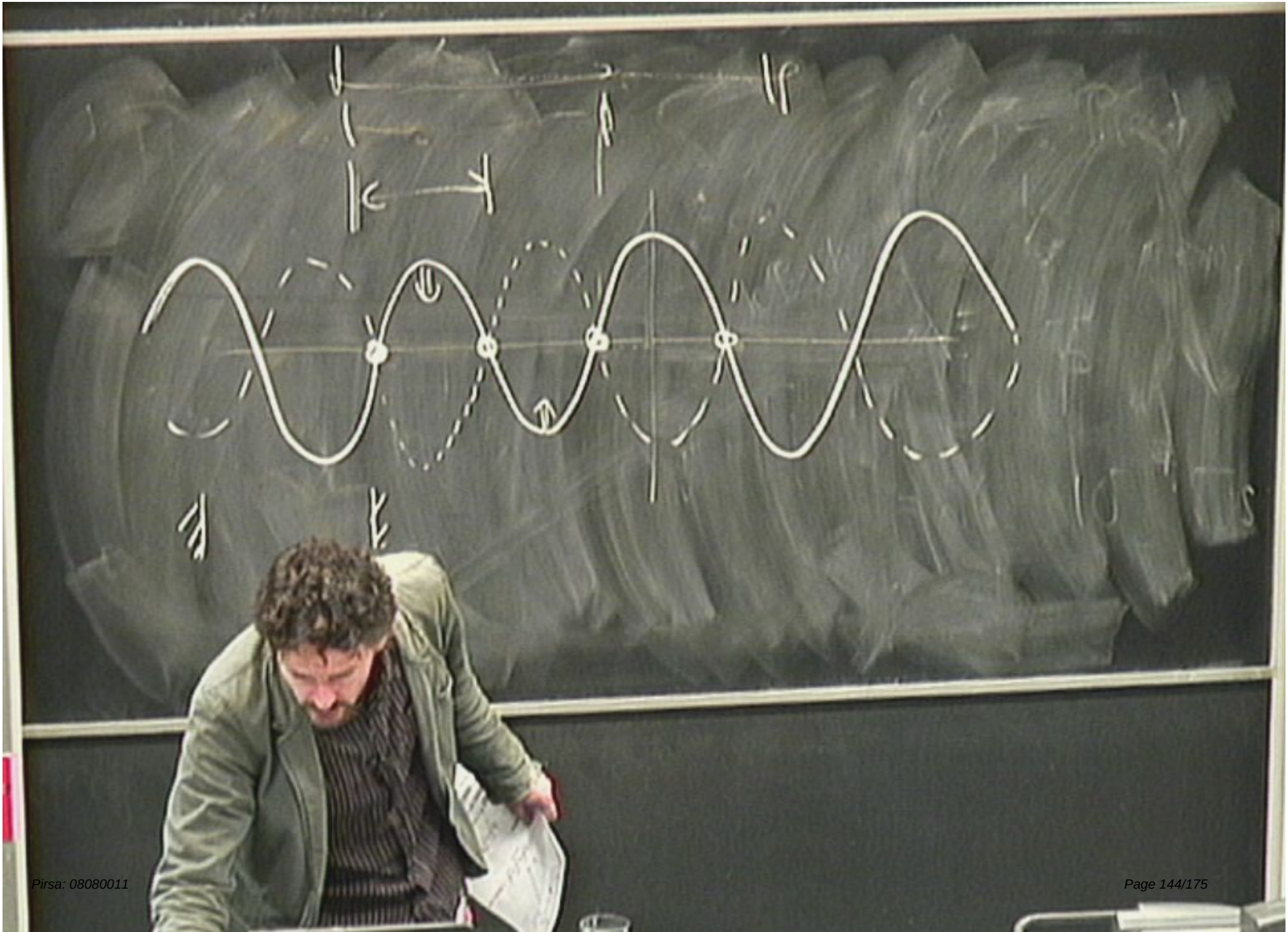








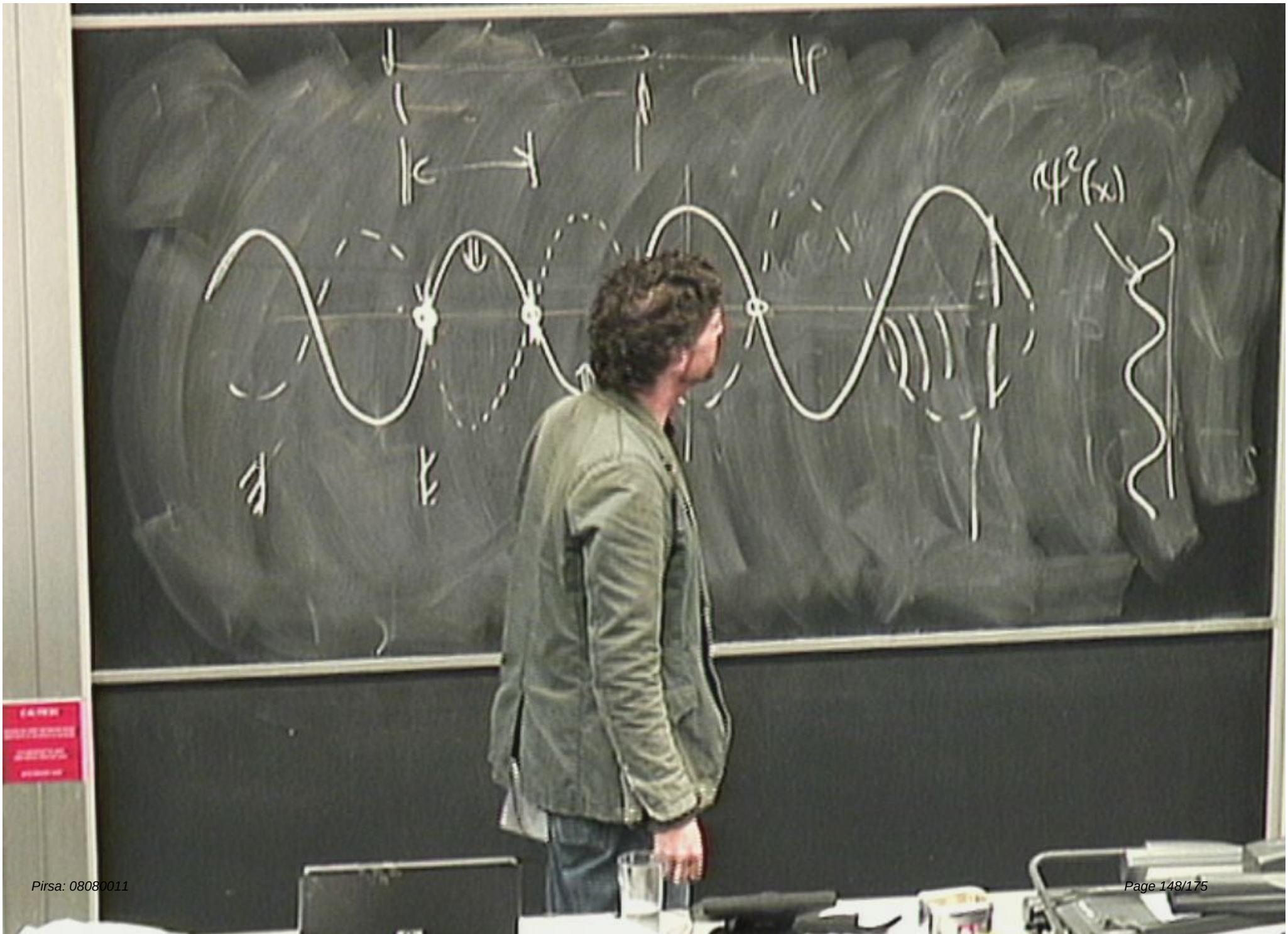


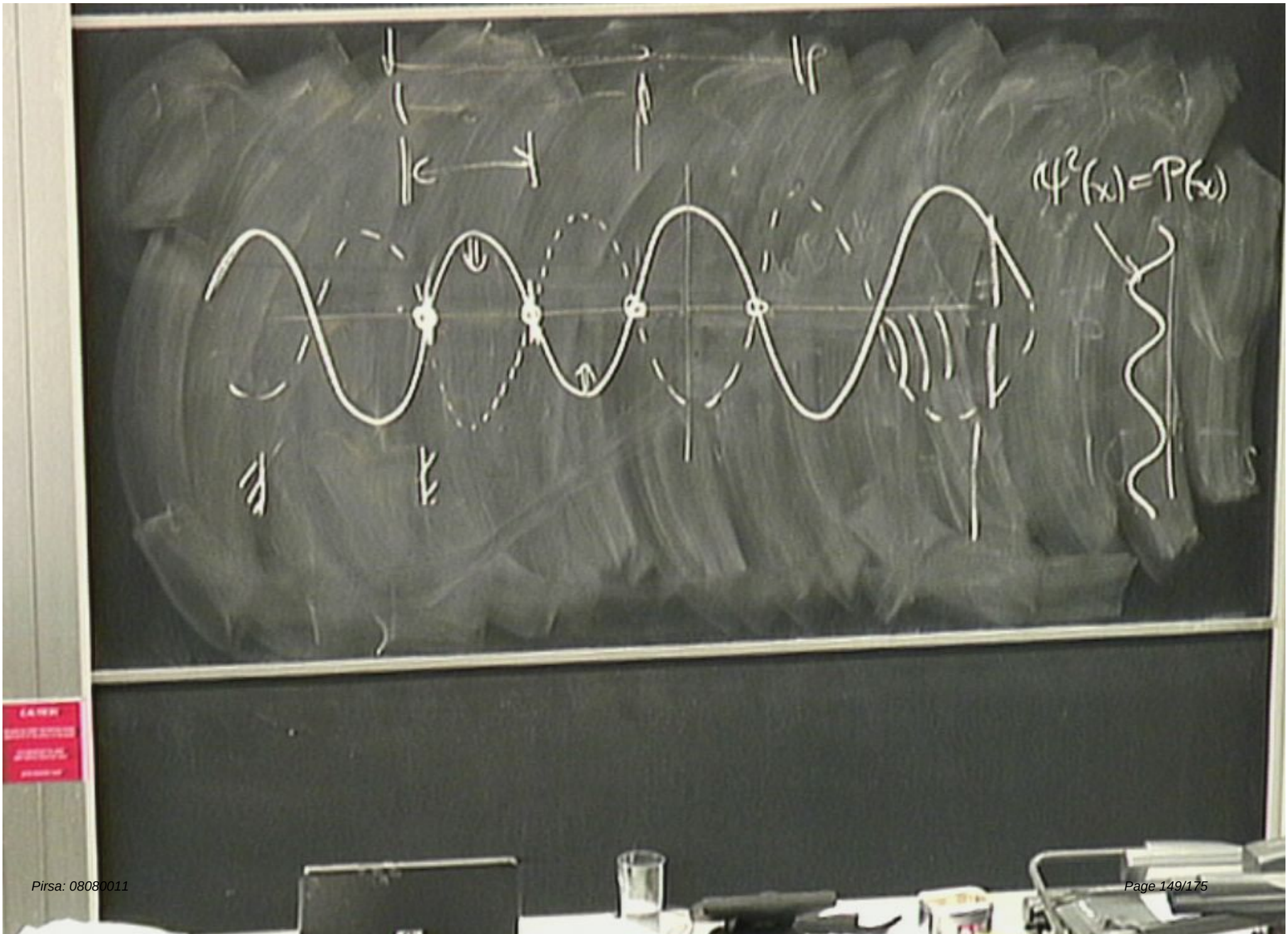


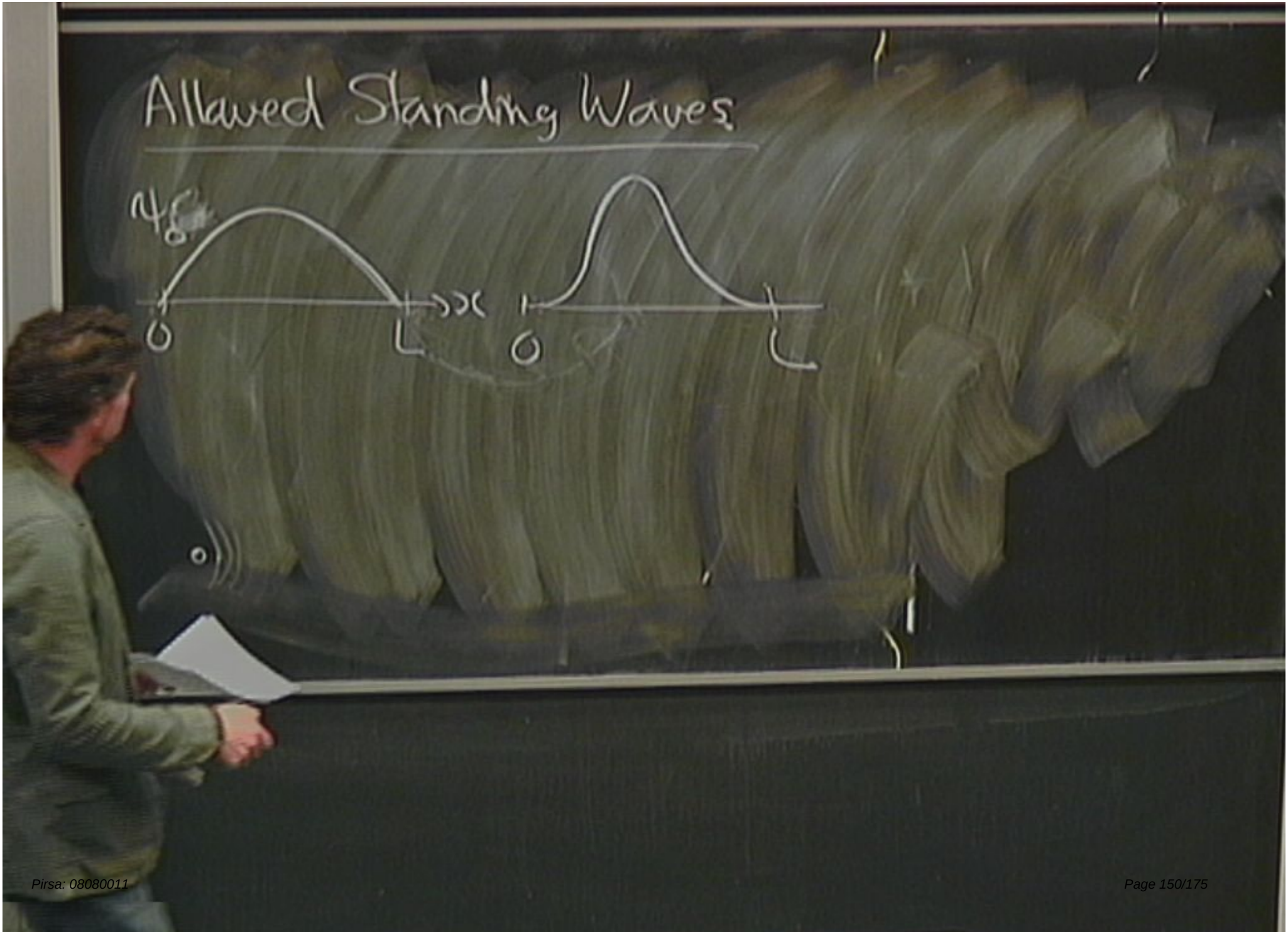
Allowed Standing Waves

Allowed Standing Waves

Allowed Standing Waves

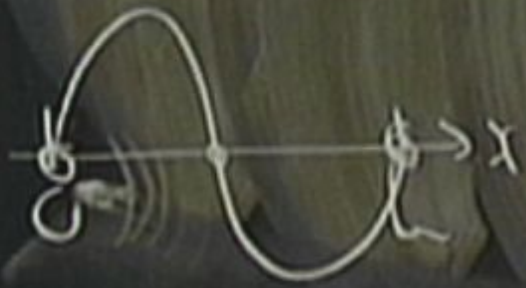

$\psi^2(x)$


$\psi^2(x) = P(x)$


Allowed Standing Waves
ψ
0
L
0

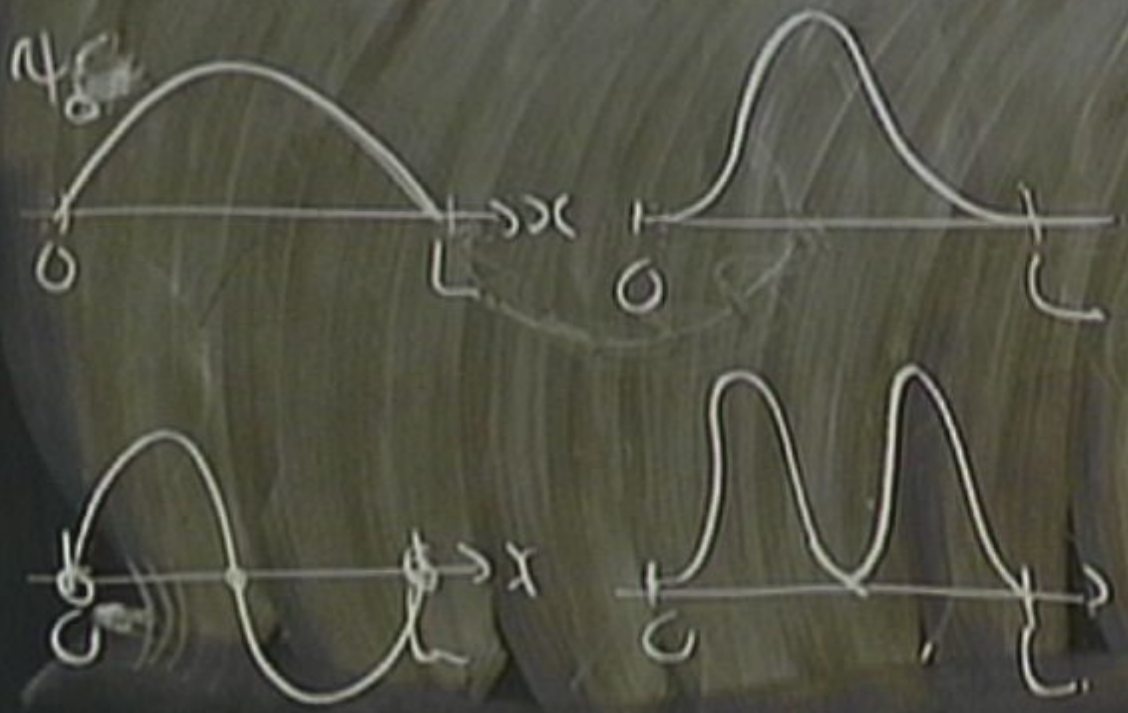
Allowed Standing Waves

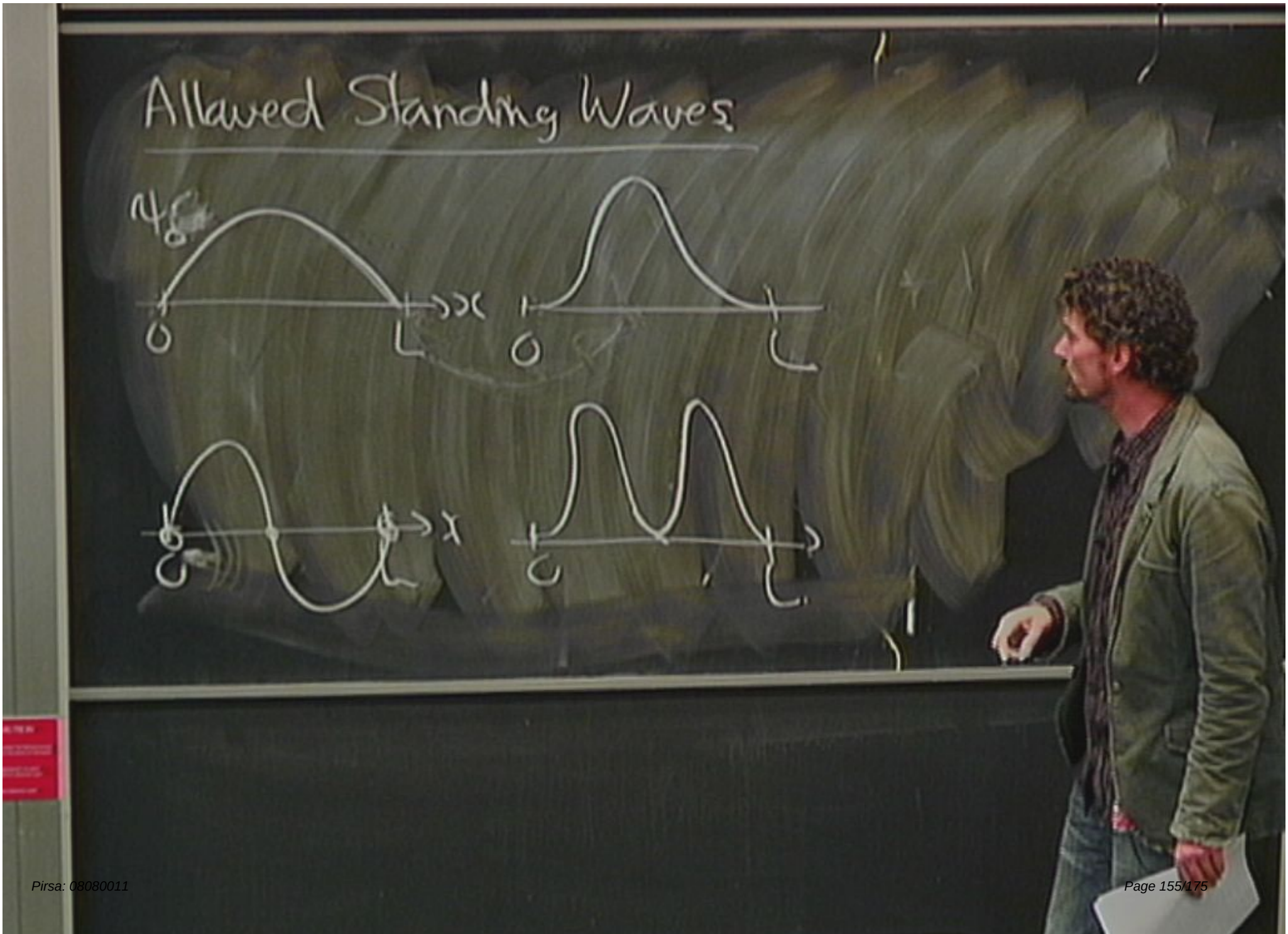
Allowed Standing Waves

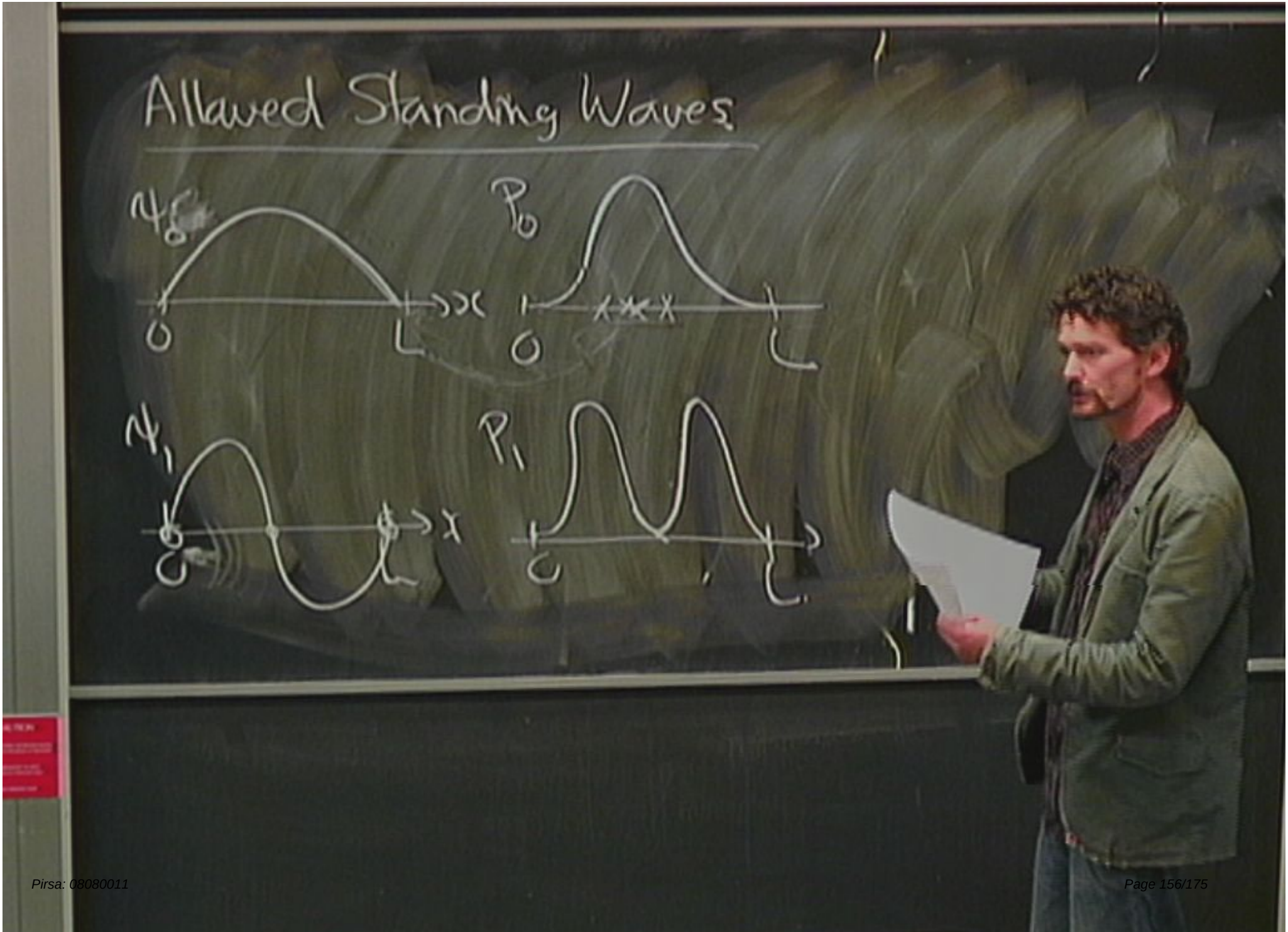


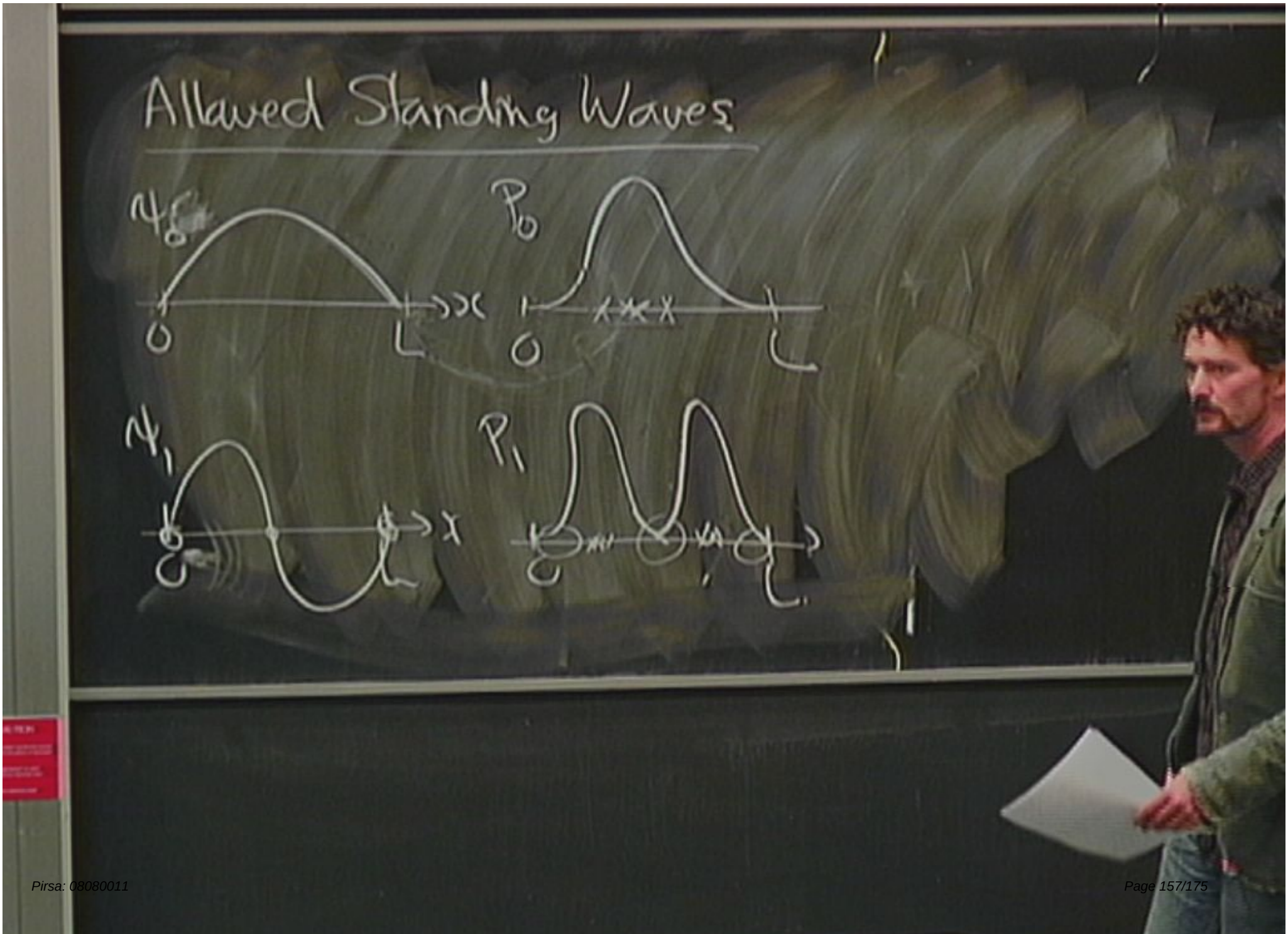
Allowed Standing Waves

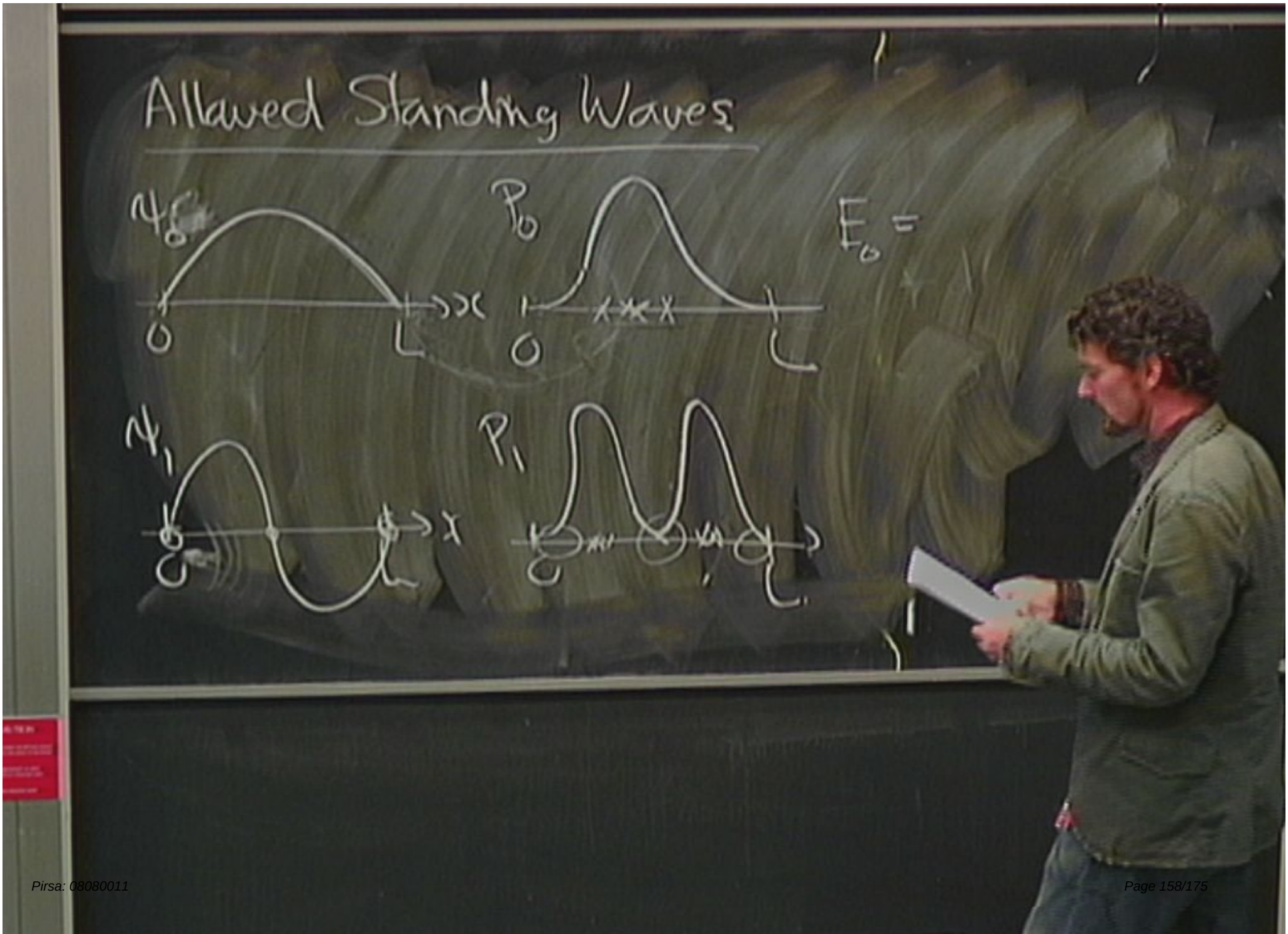
Allowed Standing Waves

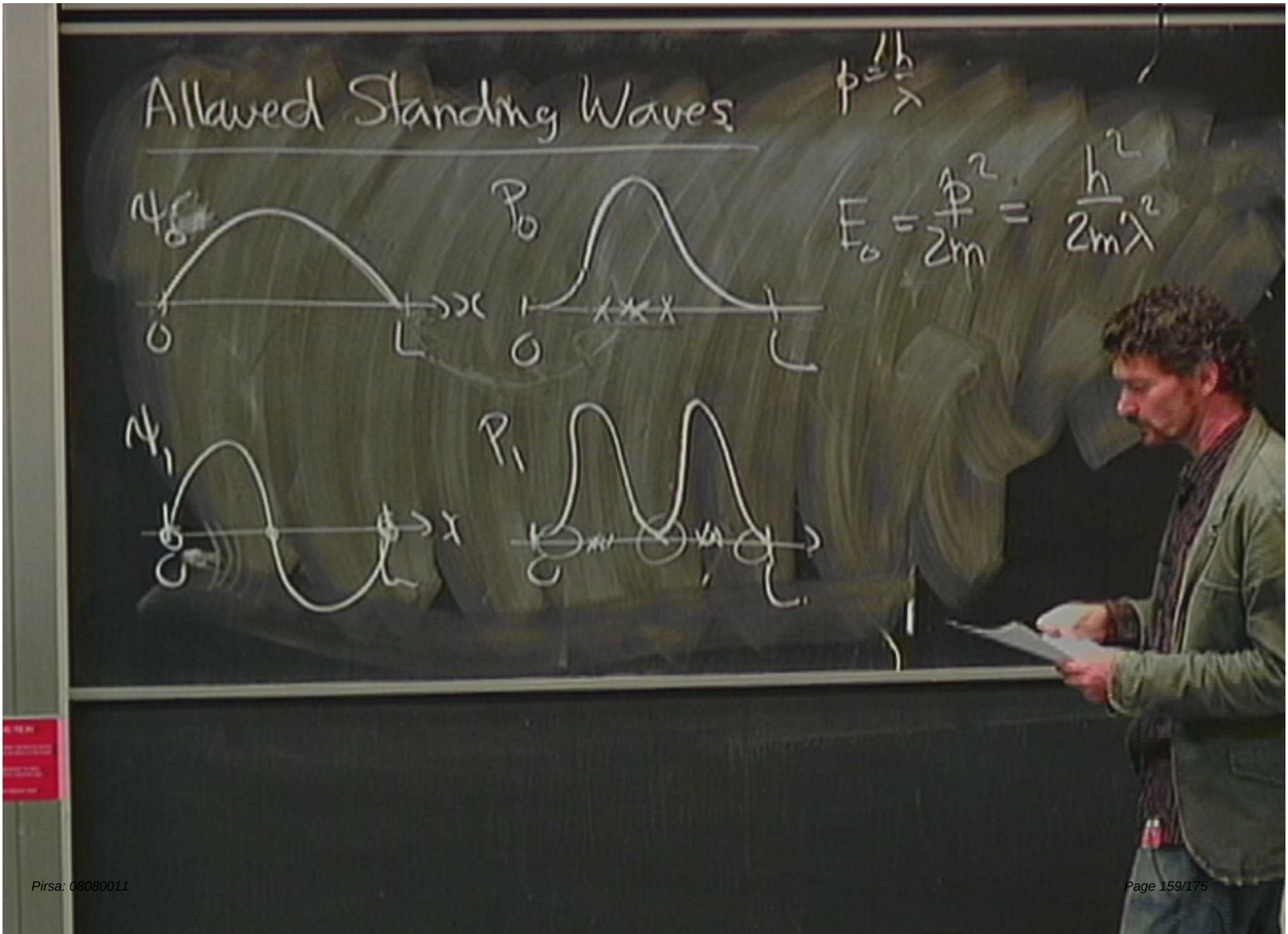


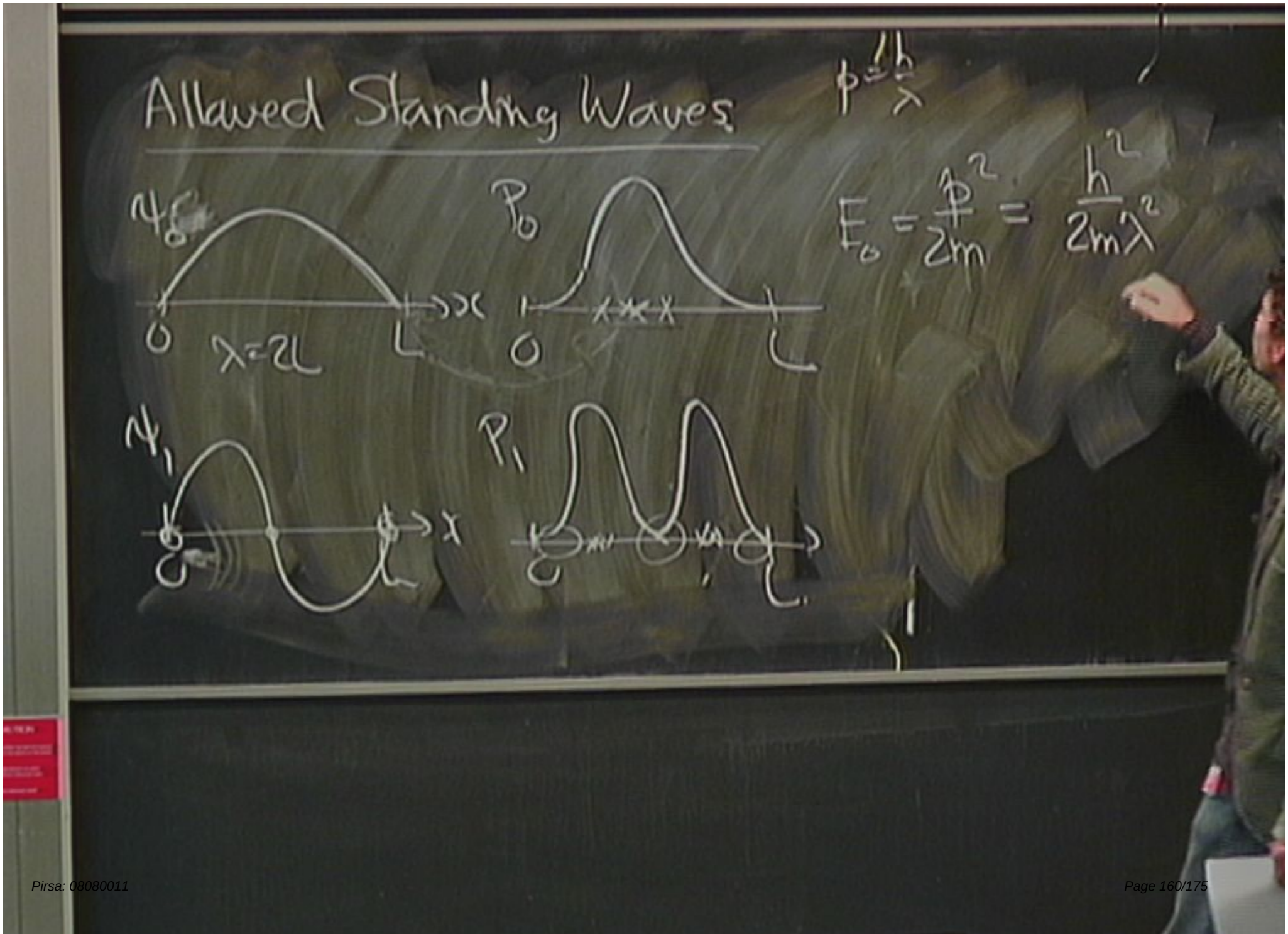

Allowed Standing Waves


Allowed Standing Waves
ψ_0
P_0
0
L
0
ψ_1
P_1
0
L


Allowed Standing Waves
ψ_0
P_0
0
L
0
ψ_1
P_1
0
x

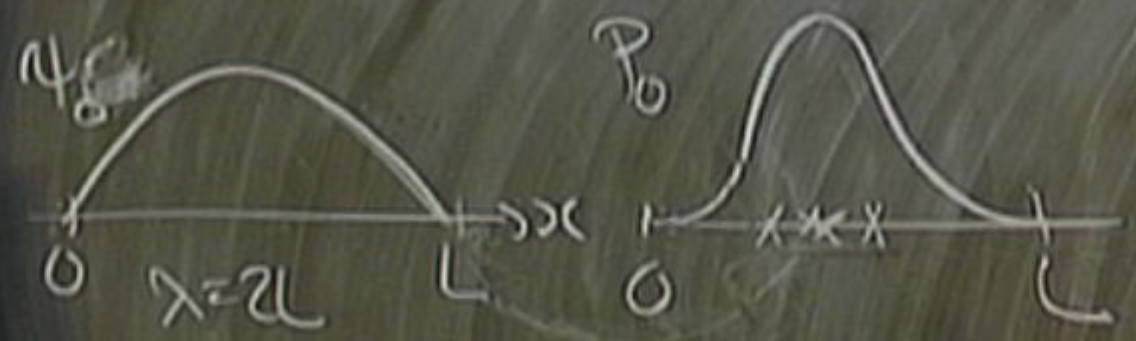

Allowed Standing Waves
ψ_0
P_0
$E_0 =$
0
L
0
ψ_1
P_1


Allowed Standing Waves
$p = \frac{h}{\lambda}$
$E_0 = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$
ψ_0
P_0
0
L
0
L
ψ_1
P_1
0
x
0
L

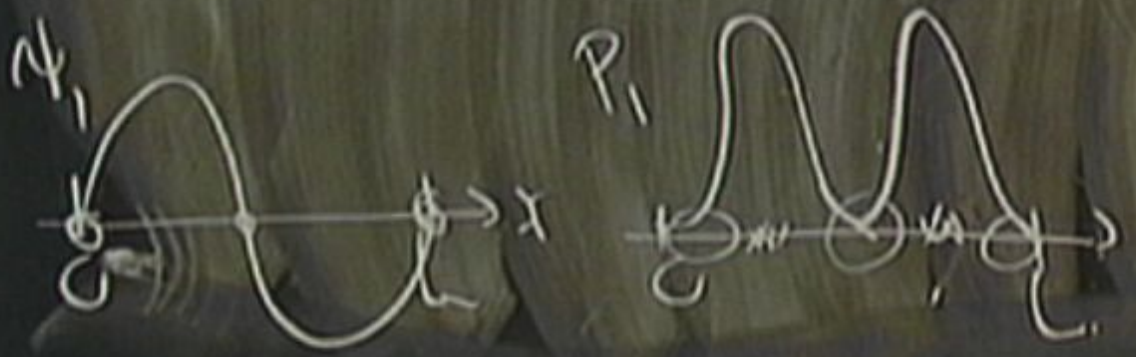

Allowed Standing Waves
$p = \frac{h}{\lambda}$
ψ_0
P_0
$E_0 = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$
0
$\lambda = 2L$
L
0
L
ψ_1
P_1
x

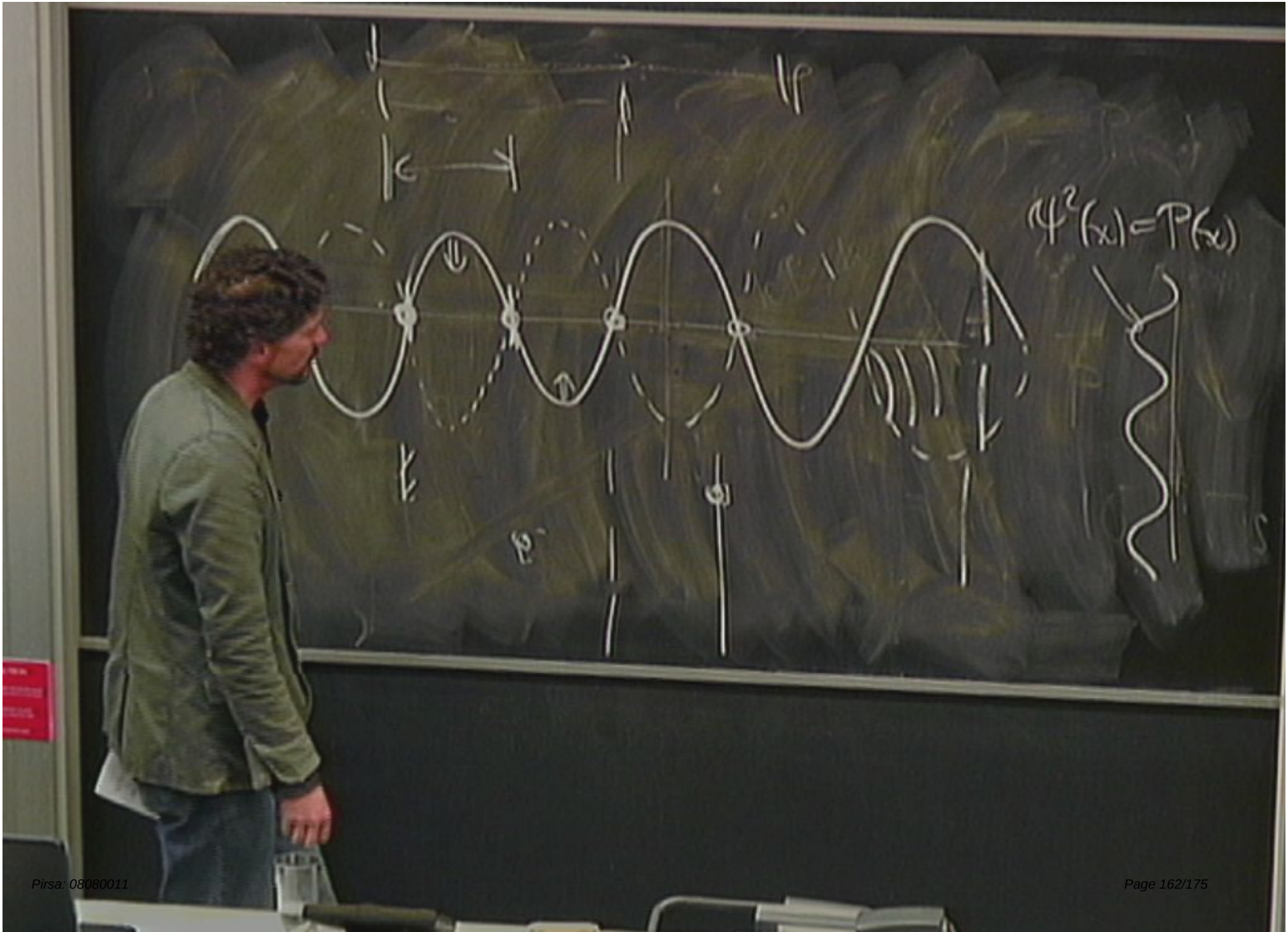
Allowed Standing Waves

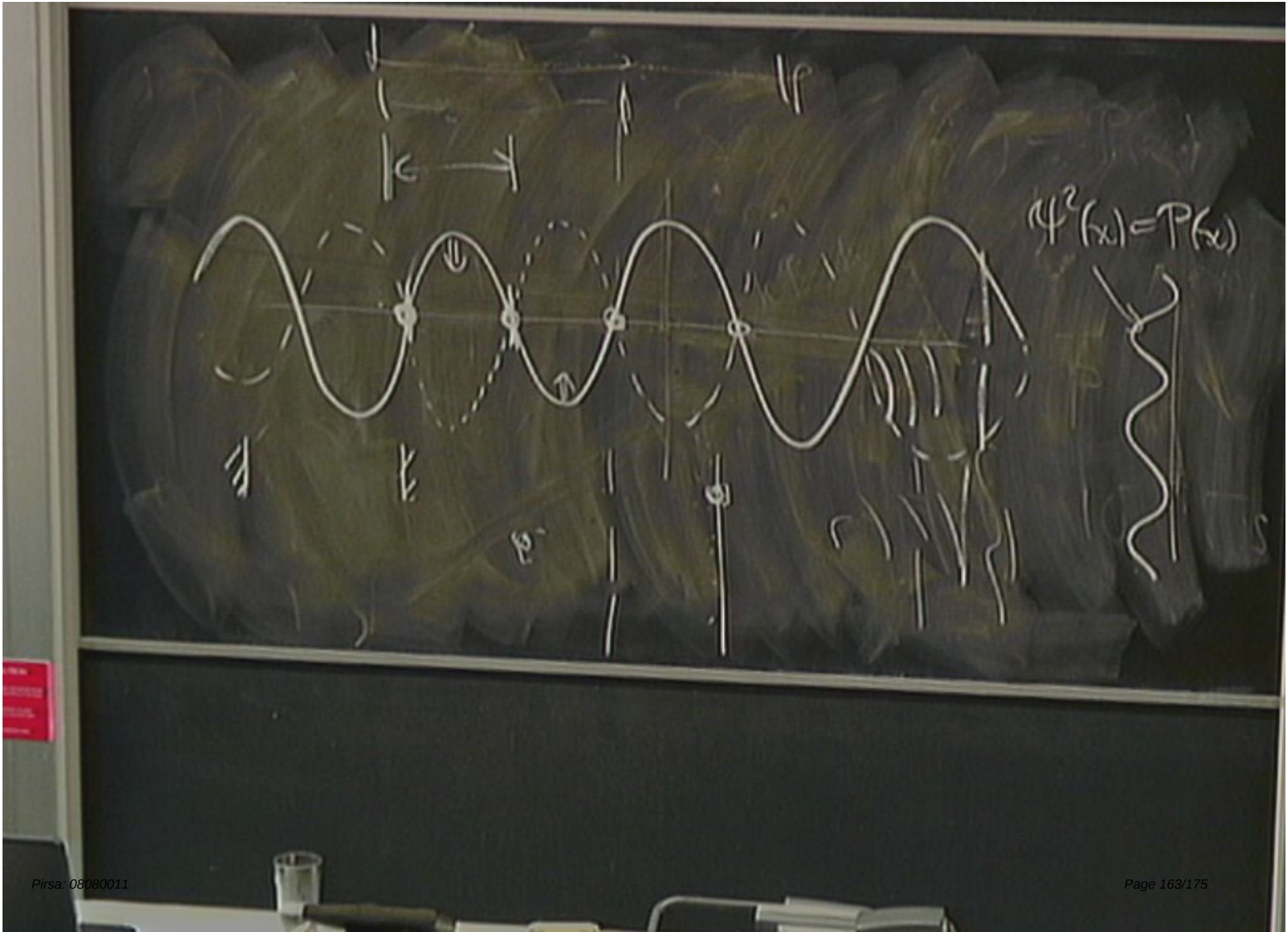
$p = \frac{h}{\lambda}$



$E_0 = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2} = \frac{h^2}{8mL^2}$

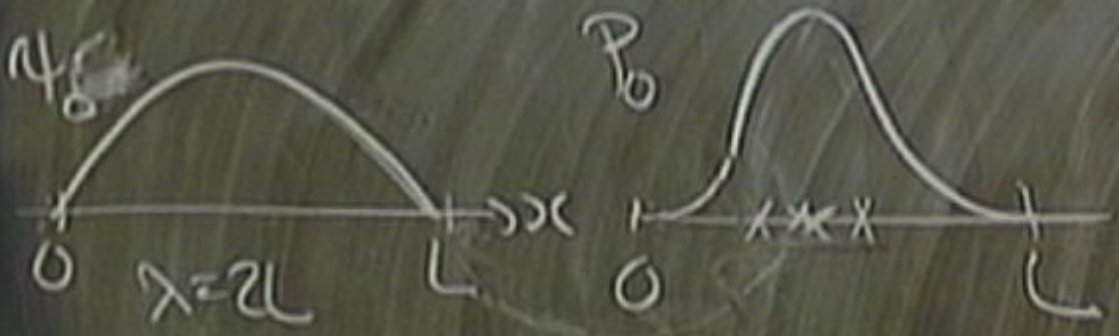



$\psi^2(x) = P(x)$

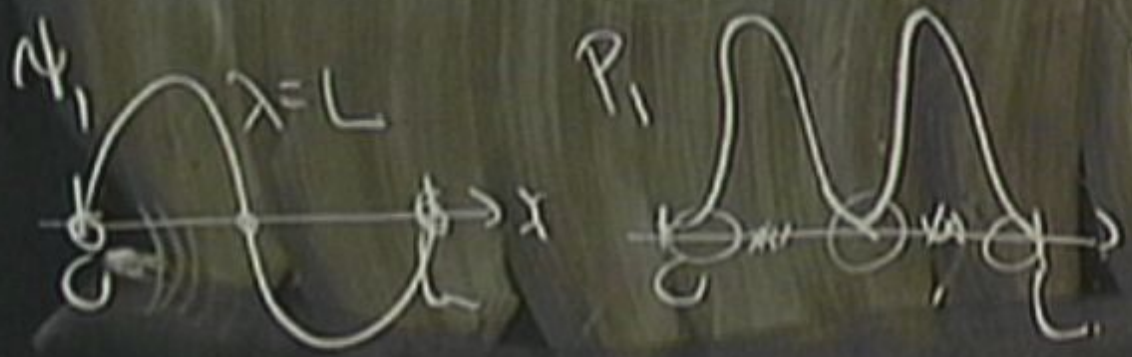

$\psi^2(x) = P(x)$

Allowed Standing Waves

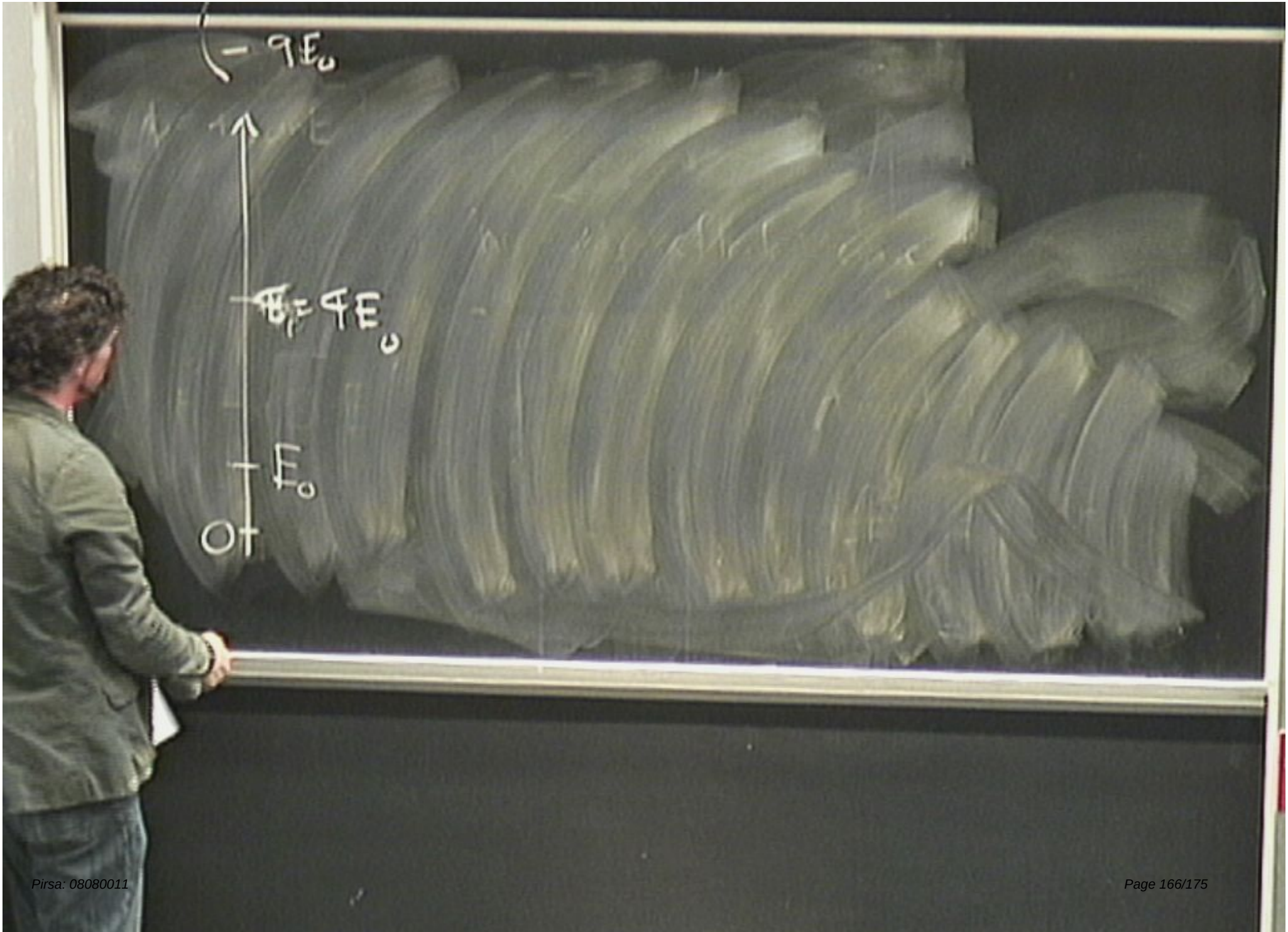
$p = \frac{h}{\lambda}$

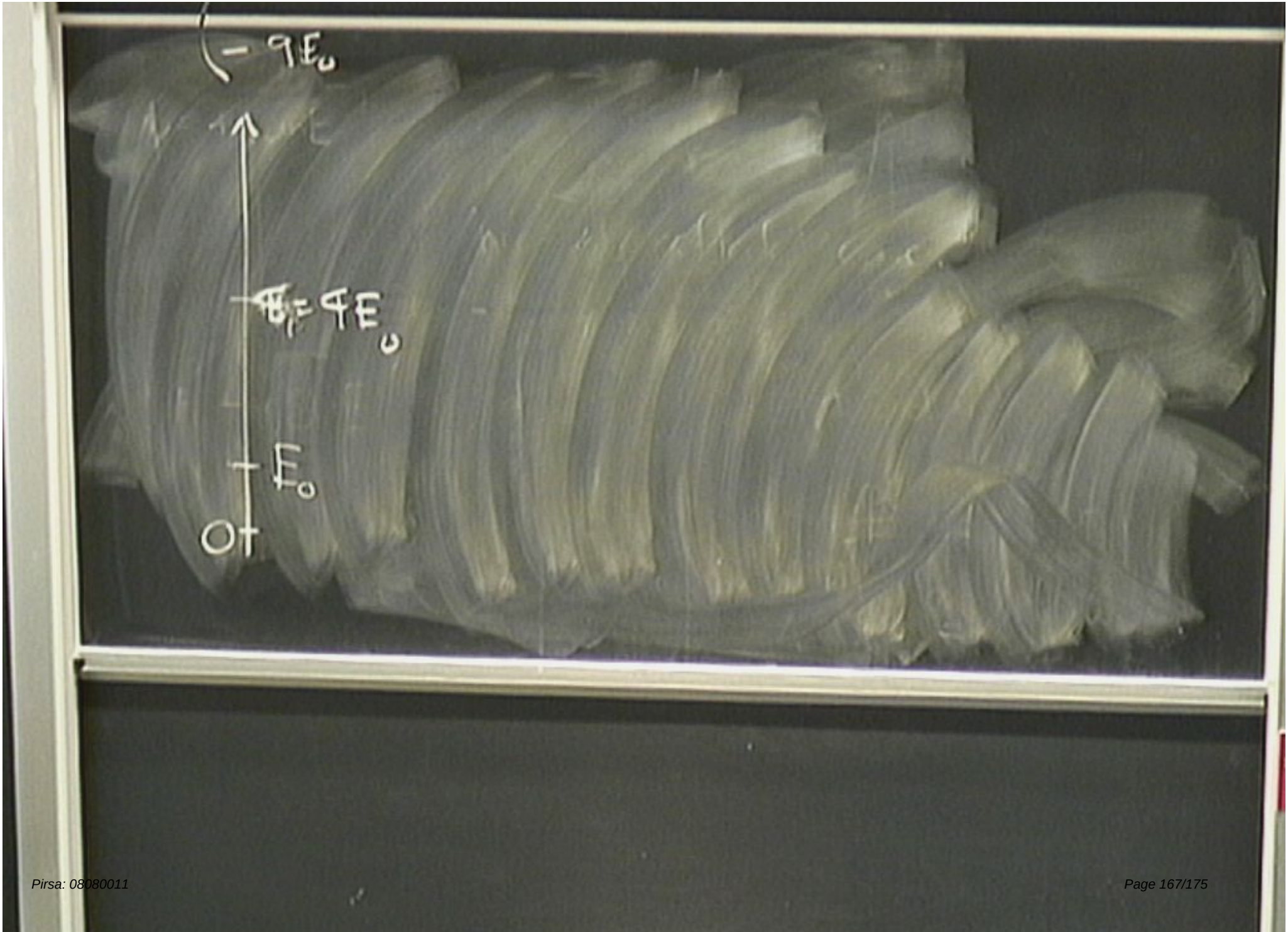


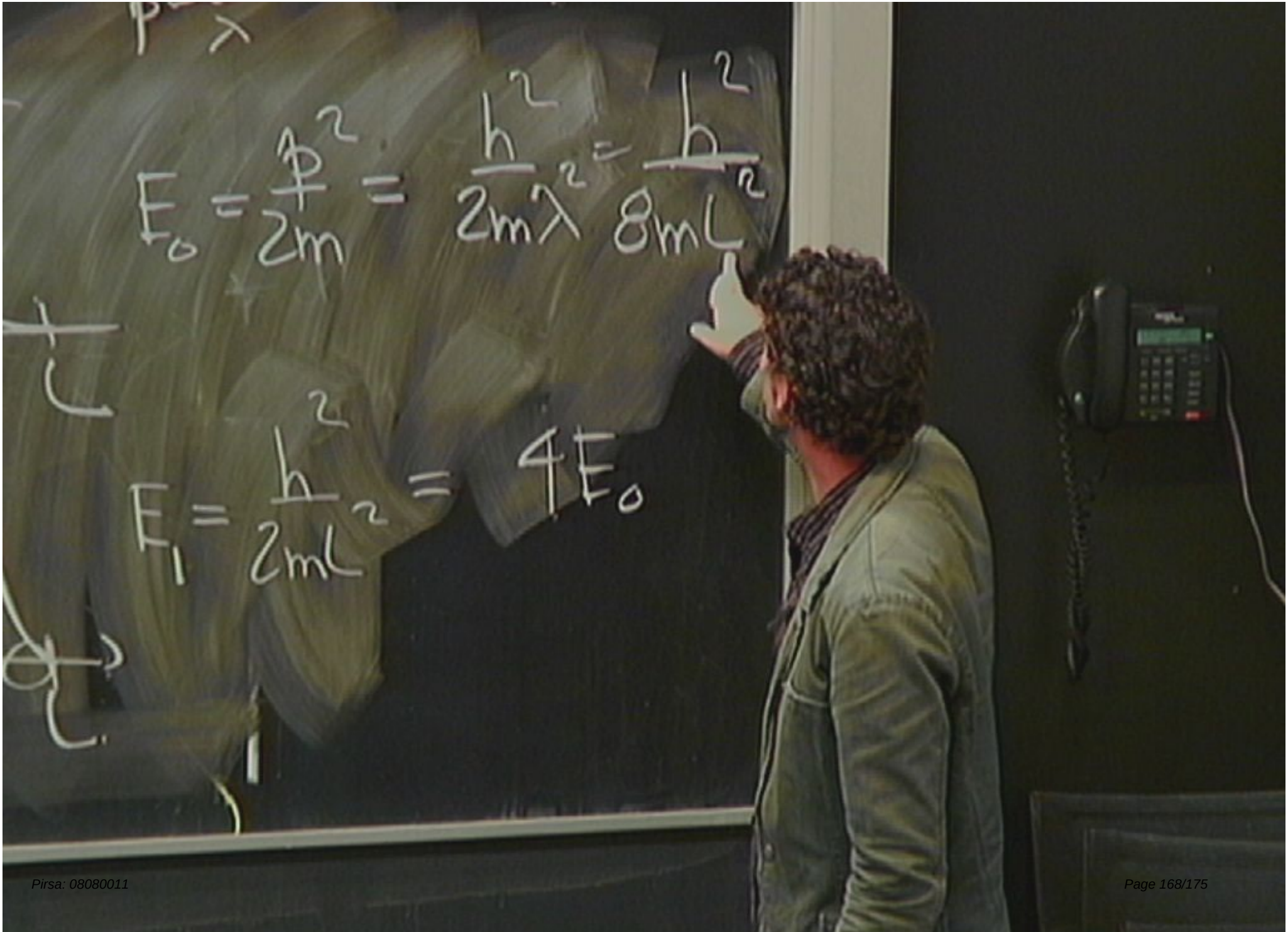
$E_0 = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2} = \frac{h^2}{8mL^2}$

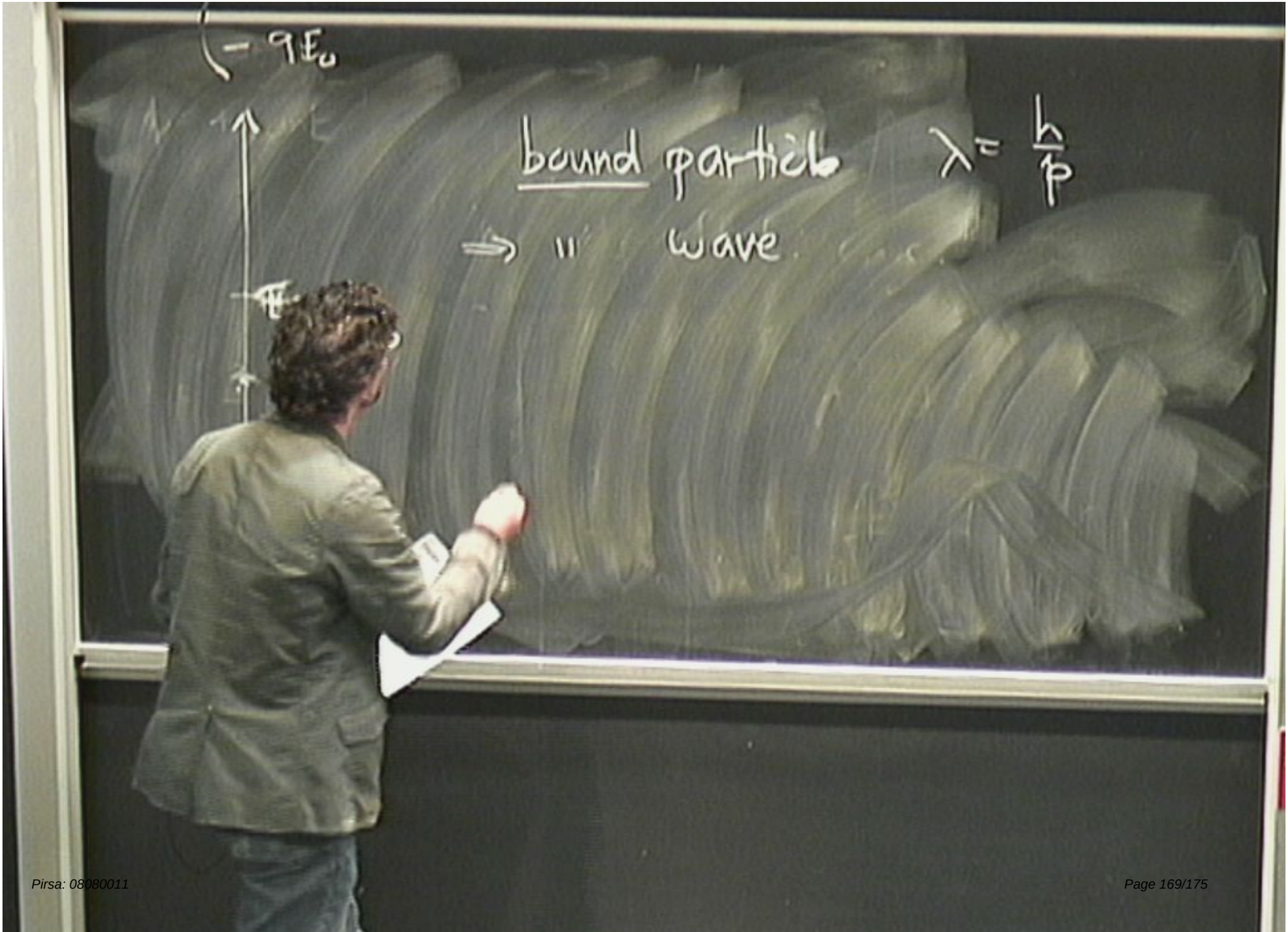


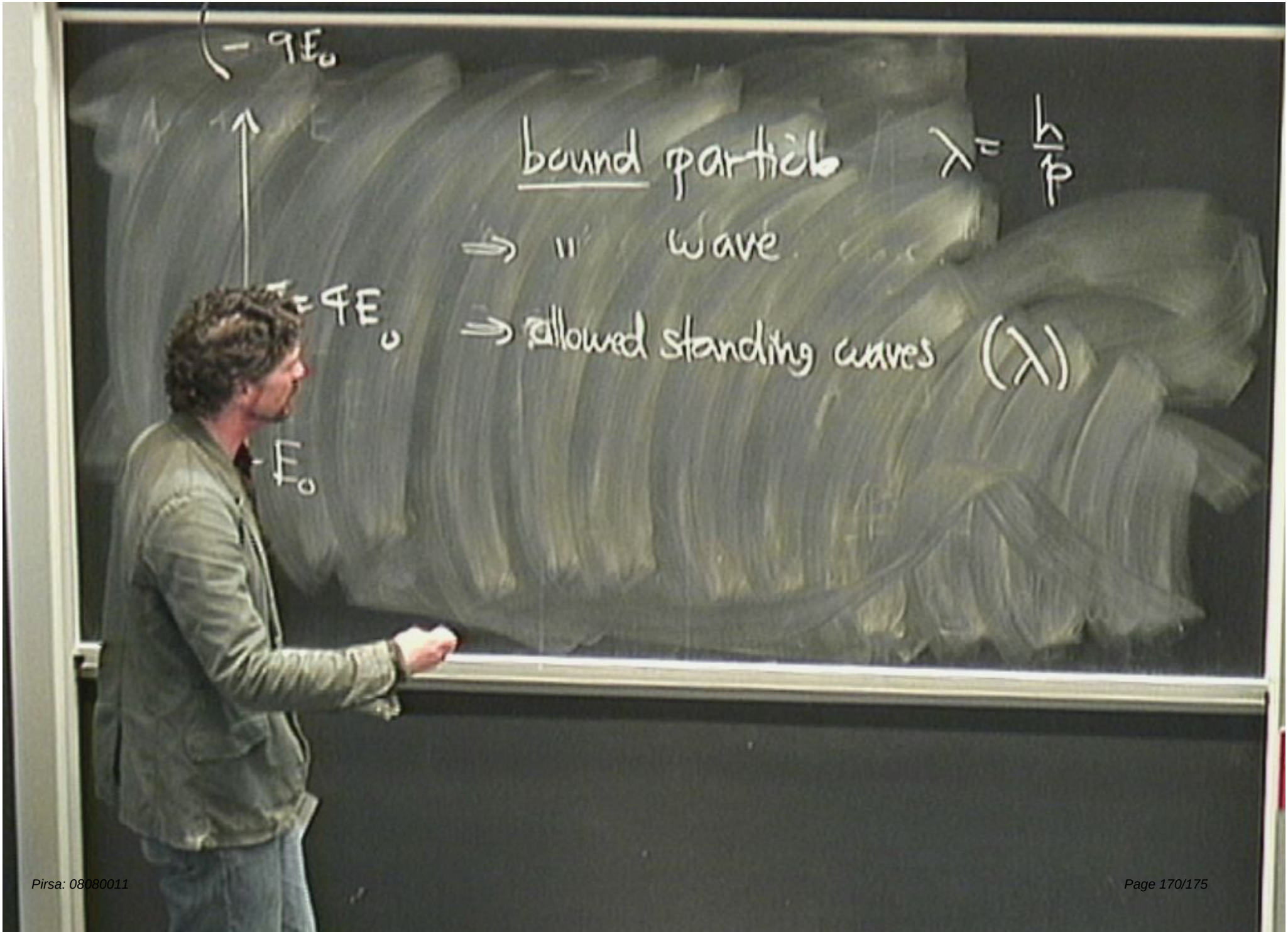
$E_1 = \frac{h^2}{2mL^2} =$

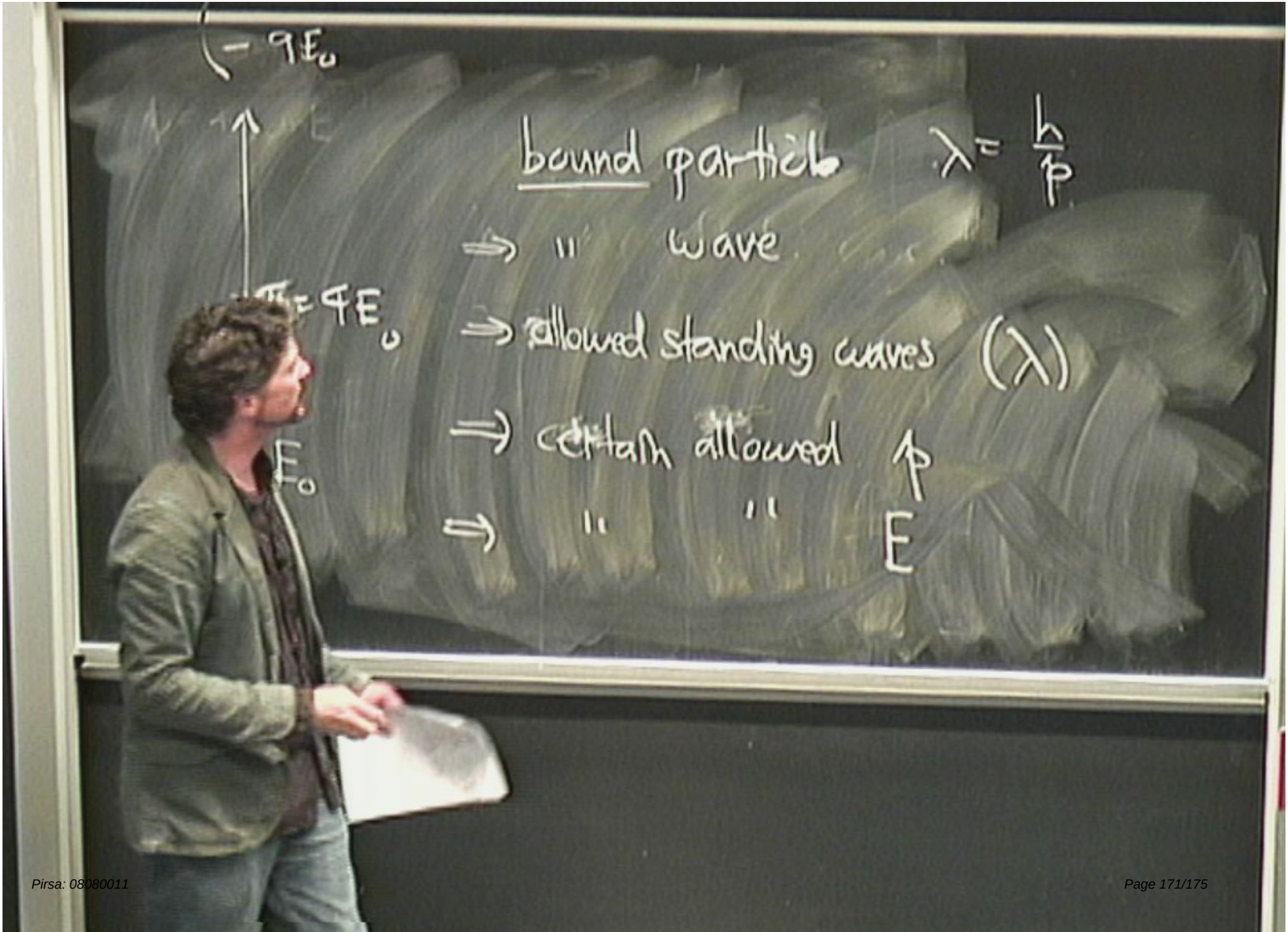

$-qE_0$
qE_0
E_0
O

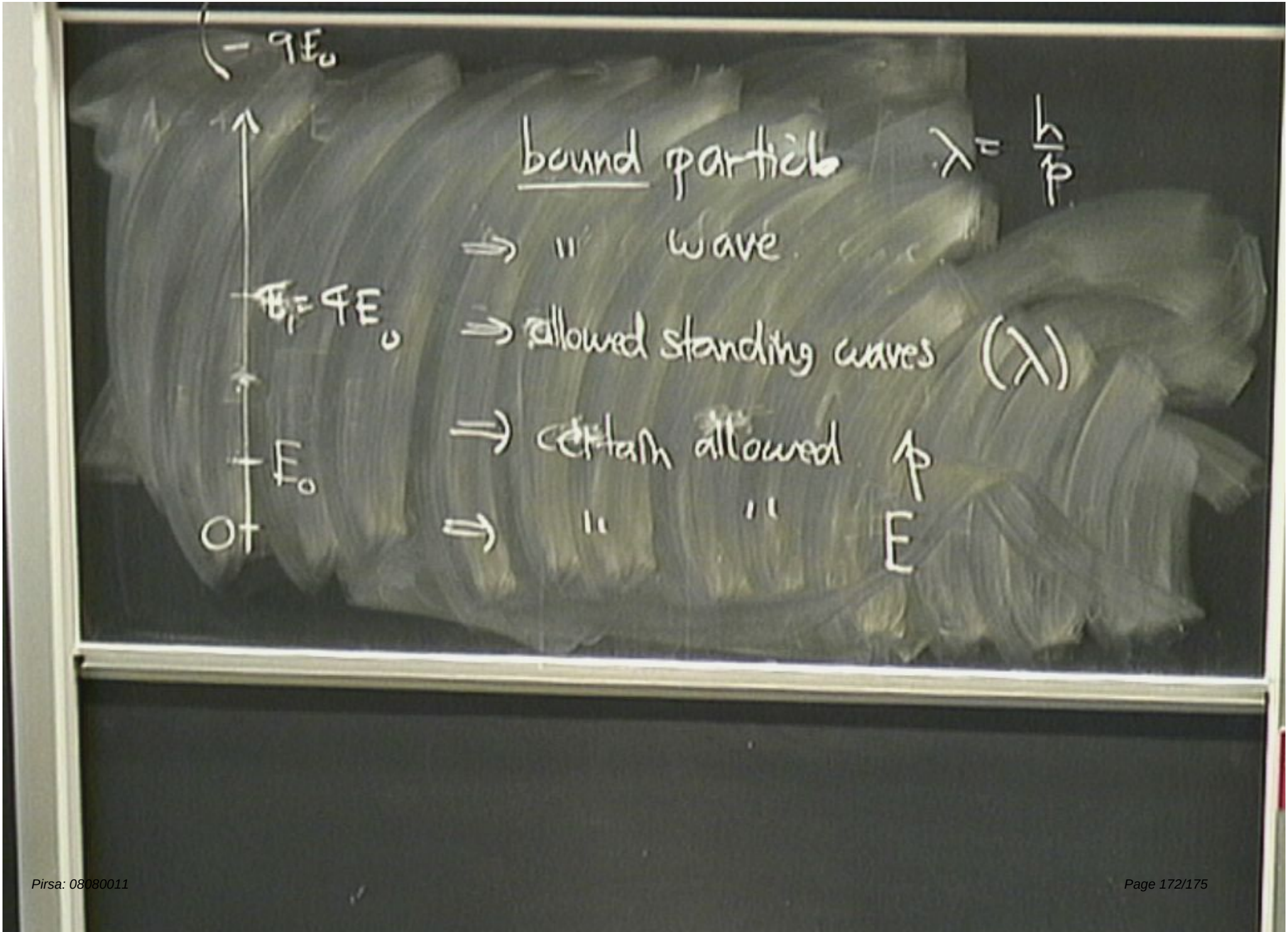

$-qE_0$
qE_0
E_0
O

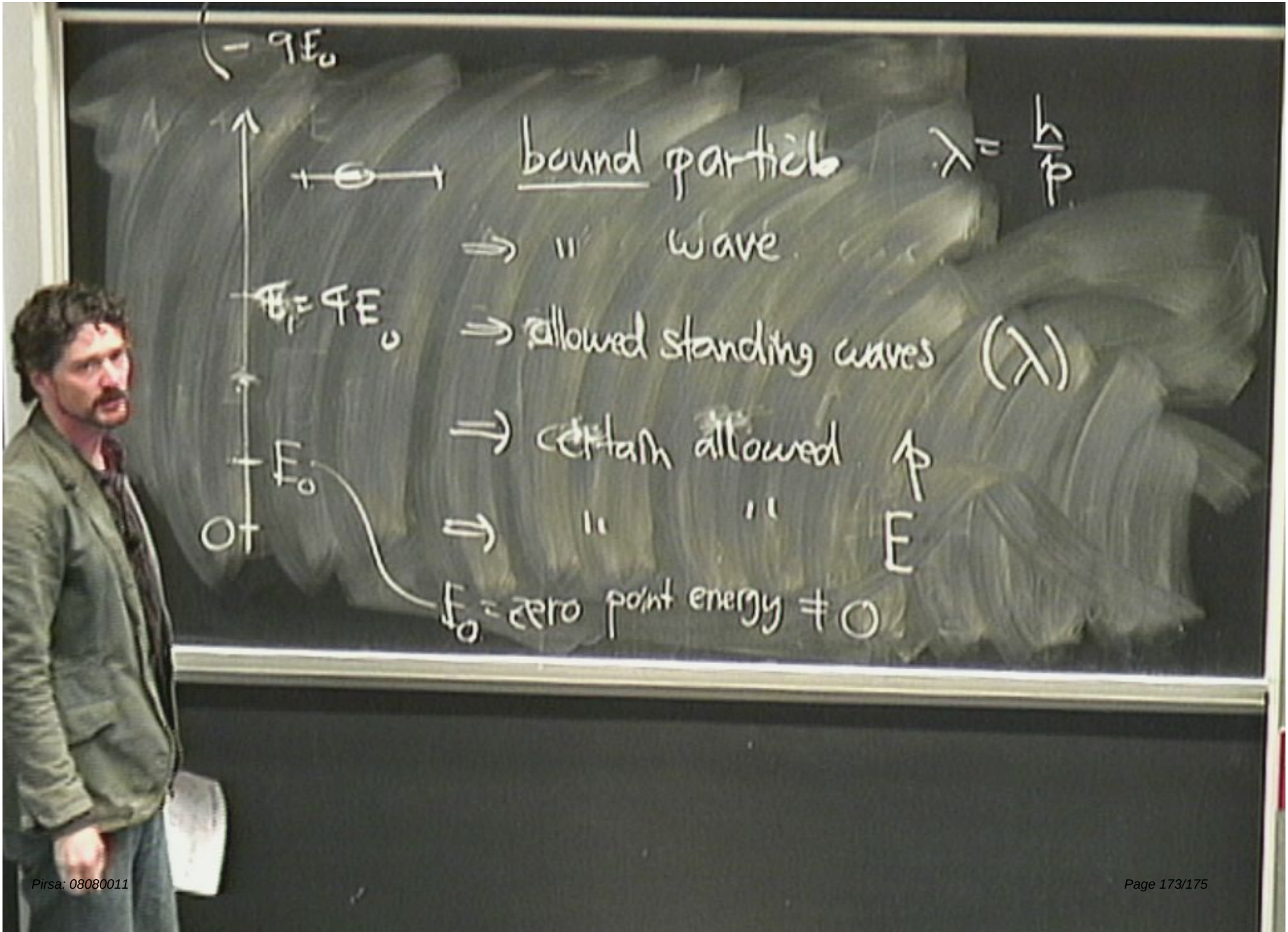

$E_0 = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2} = \frac{h^2}{8mL^2}$
$E_1 = \frac{h^2}{2mL^2} = 4E_0$

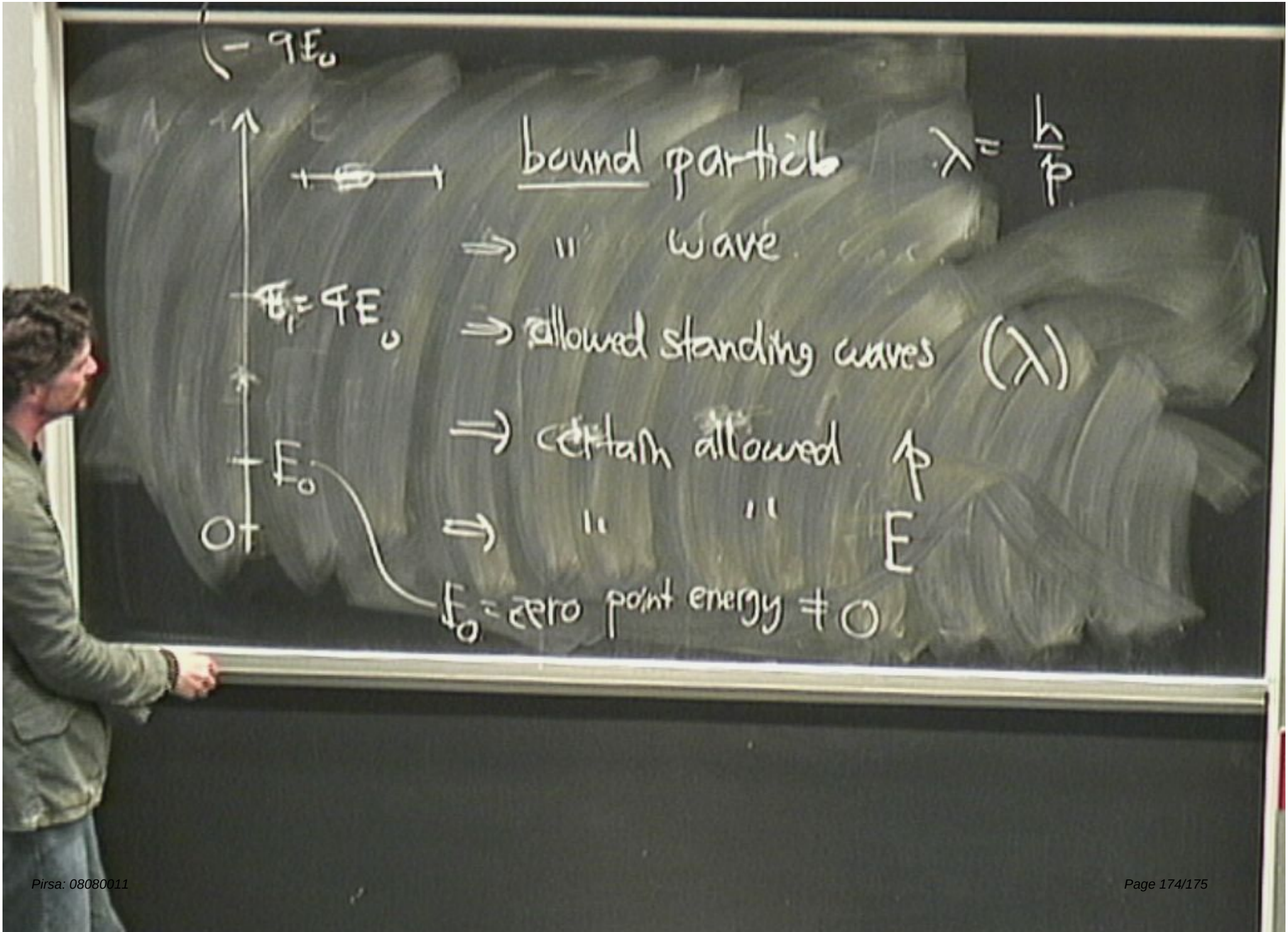

$-qE_0$
bound particle
$\lambda = \frac{h}{p}$
$\Rightarrow$ " wave

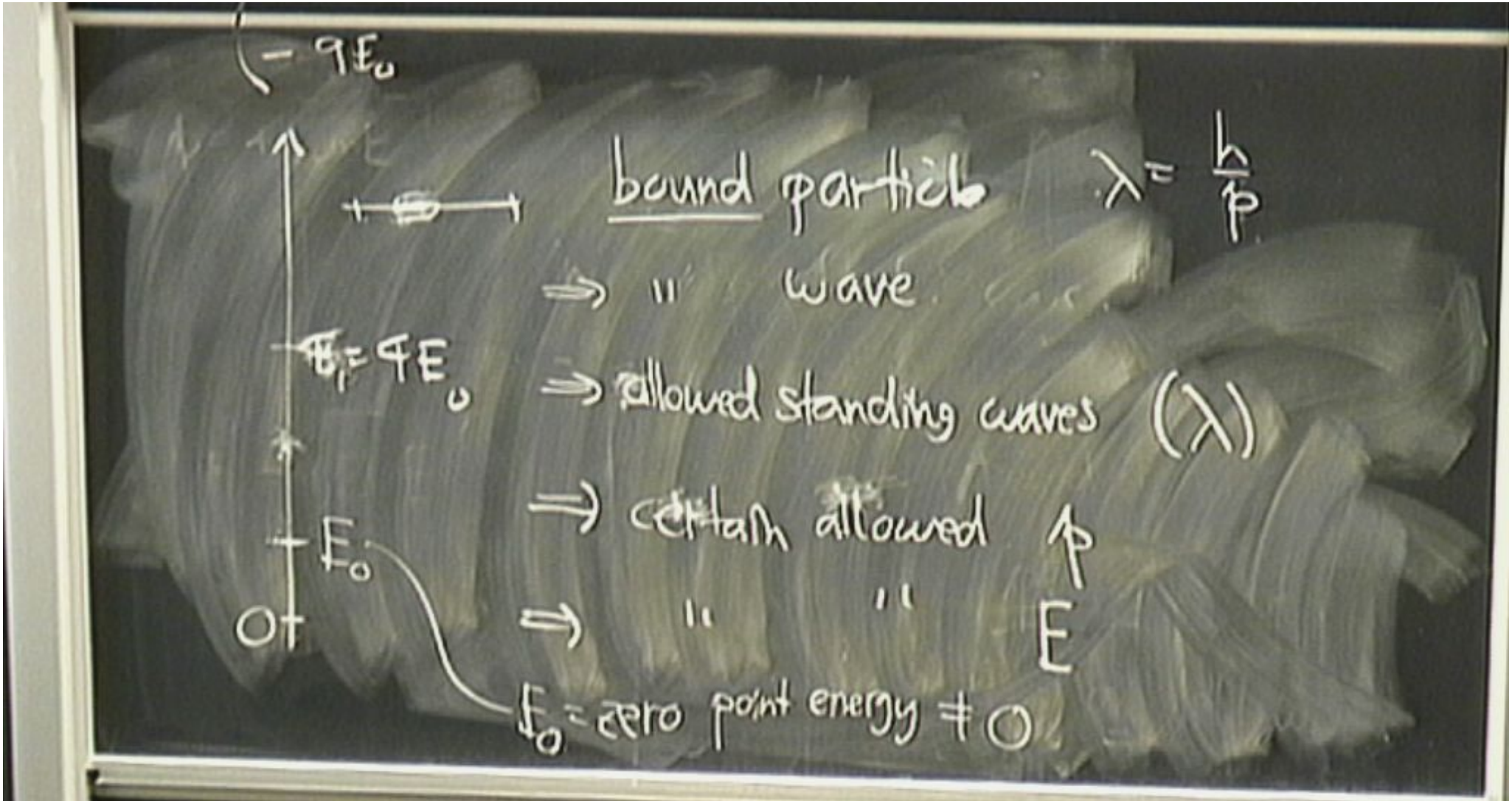

$-qE_0$
bound particle
$\lambda = \frac{h}{p}$
$\Rightarrow$ " wave
$= qE_0$
$\Rightarrow$ allowed standing waves (λ)
$-E_0$


$-qE_0$
bound particle
$\lambda = \frac{h}{p}$
$\Rightarrow$ " wave
$= qE_0$
$\Rightarrow$ allowed standing waves (λ)
$\Rightarrow$ certain allowed
E_0
$\Rightarrow$ " "
p
E


$-qE_0$
bound particle
$\lambda = \frac{h}{p}$
$\Rightarrow$ " wave
$E_1 = qE_0$
$\Rightarrow$ allowed standing waves (λ)
E_0
$\Rightarrow$ certain allowed
0
$\Rightarrow$ " "
p
E


$-qE_0$
bound particle
$\lambda = \frac{h}{p}$
$\Rightarrow$ " wave
$E_1 = qE_0$
$\Rightarrow$ allowed standing waves (λ)
$\Rightarrow$ certain allowed
E_0
0
$\Rightarrow$ " "
E
p
E_0 = zero point energy $\neq 0$


$-qE_0$
bound particle
$\lambda = \frac{h}{p}$
$\Rightarrow$ " wave
$E_1 = qE_0$
$\Rightarrow$ allowed standing waves (λ)
$\Rightarrow$ certain allowed
E_0
$\Rightarrow$ " " p
0
E
E_0 = zero point energy $\neq 0$


$-qE_0$
bound particle
$\lambda = \frac{h}{p}$
$\Rightarrow$ " wave
$E_1 = qE_0$
$\Rightarrow$ allowed standing waves (λ)
$\Rightarrow$ certain allowed
E_0
$\Rightarrow$ " "
0
E
E_0 = zero point energy $\neq 0$