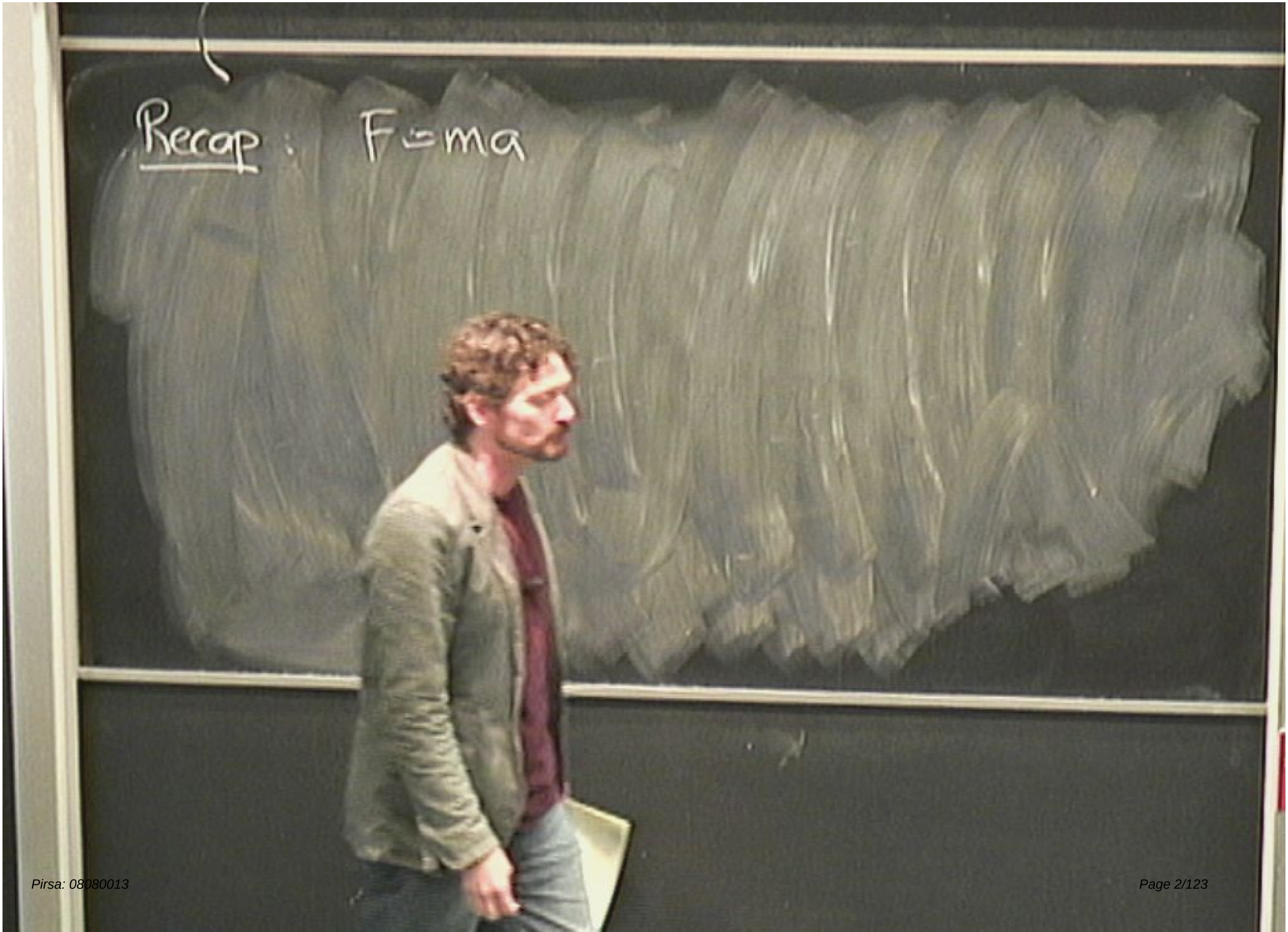
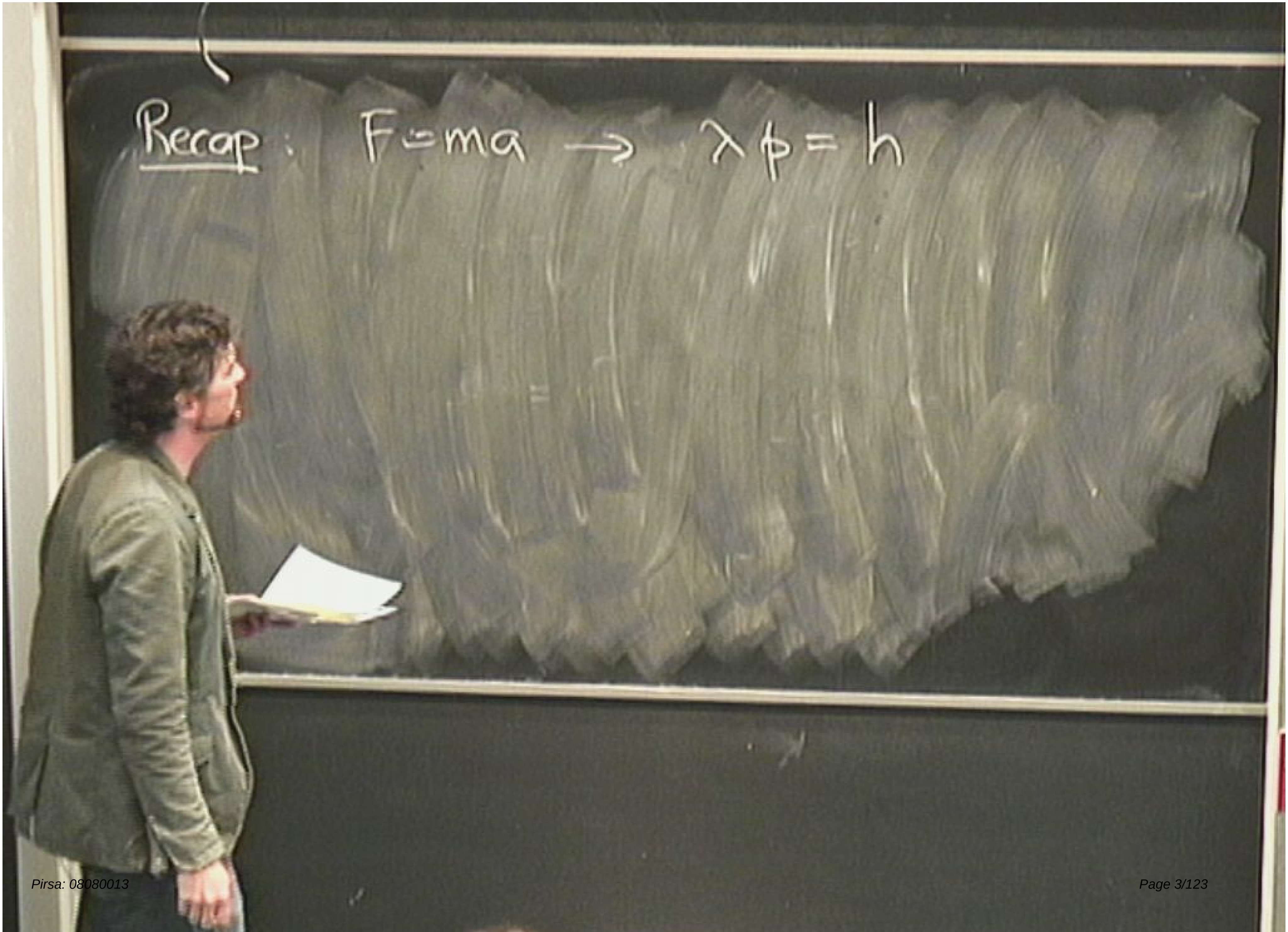
Title: Quantum 2

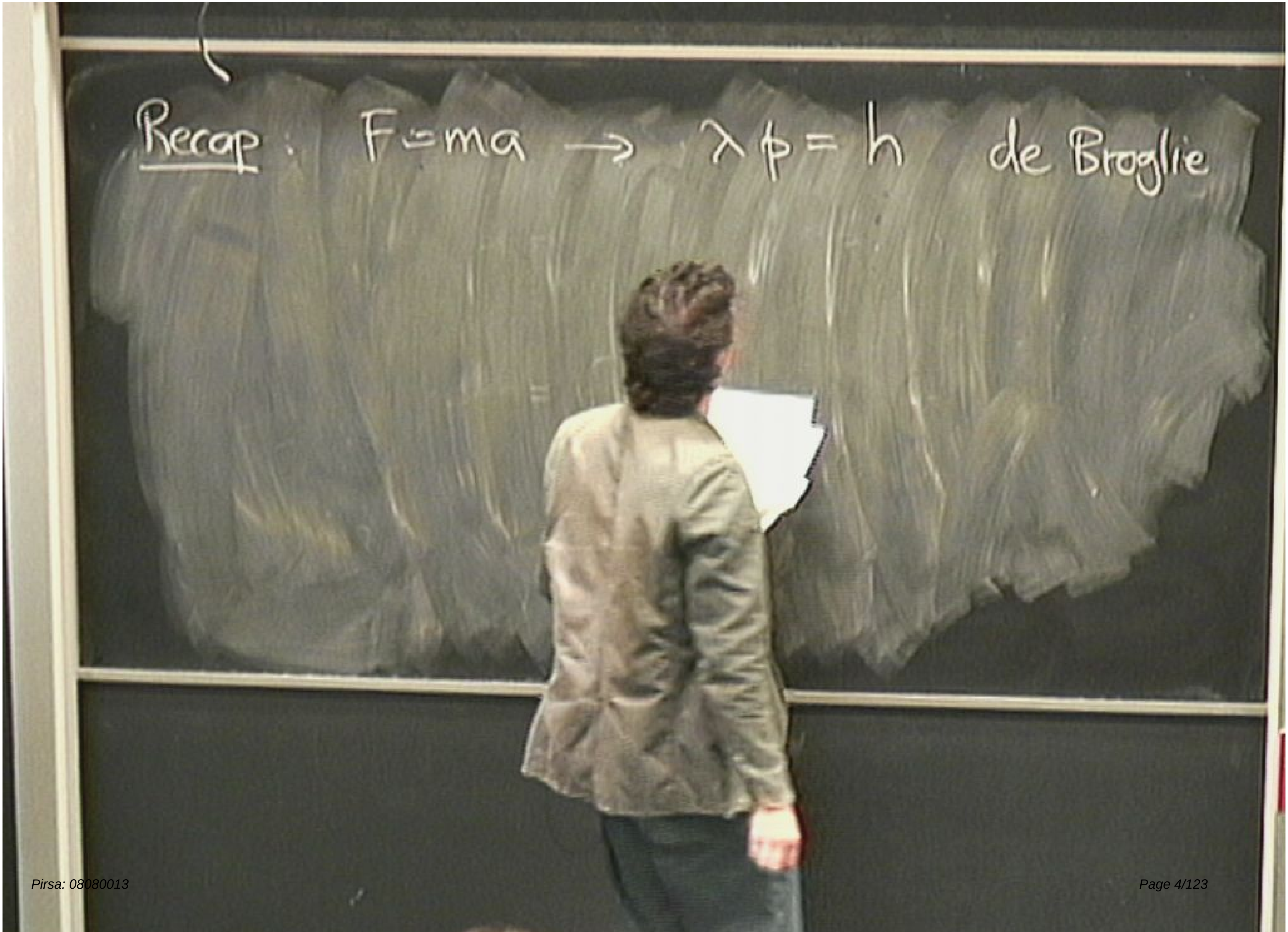
Date: Aug 11, 2008 10:30 AM

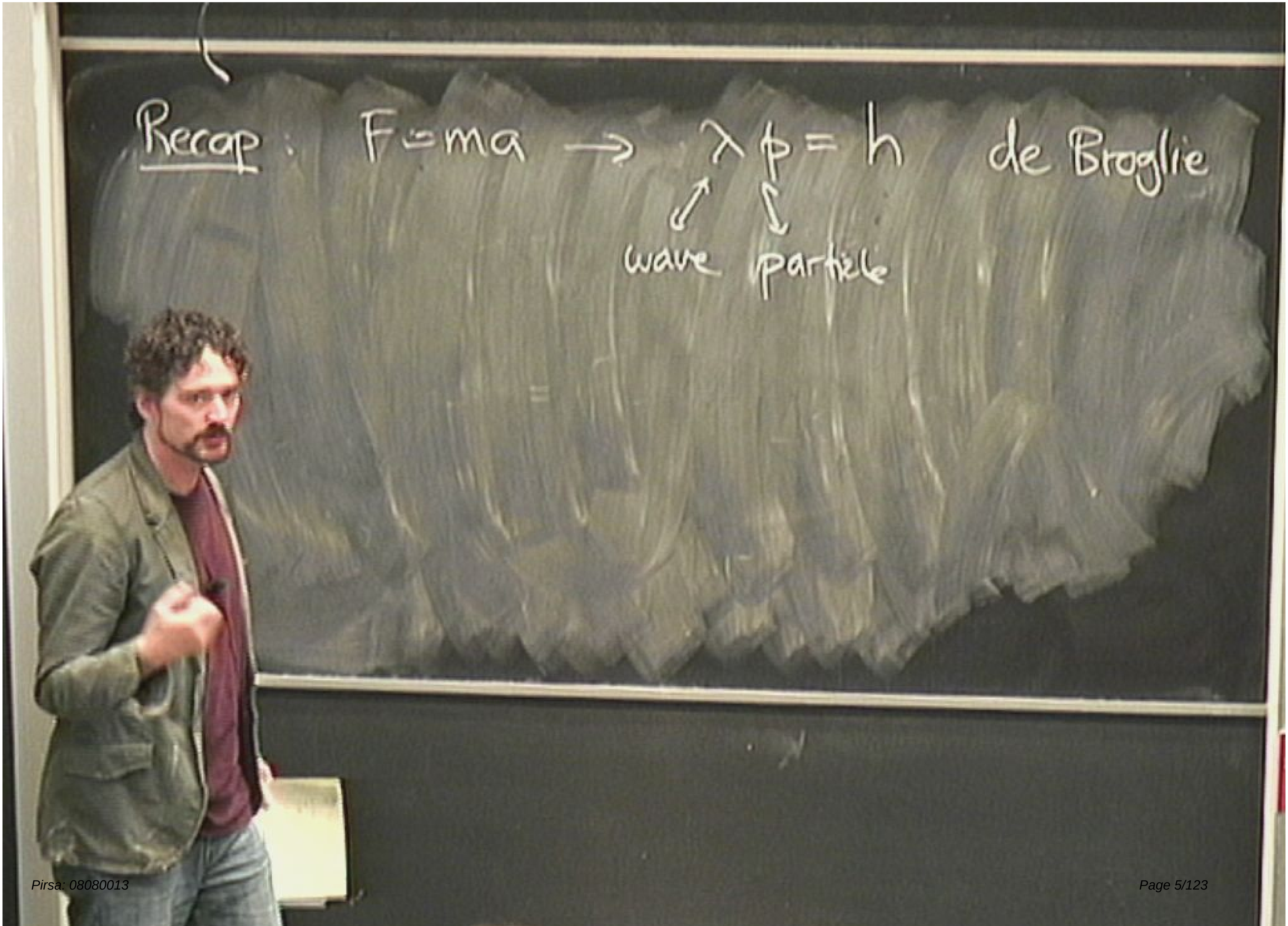
URL: http://pirsa.org/08080013

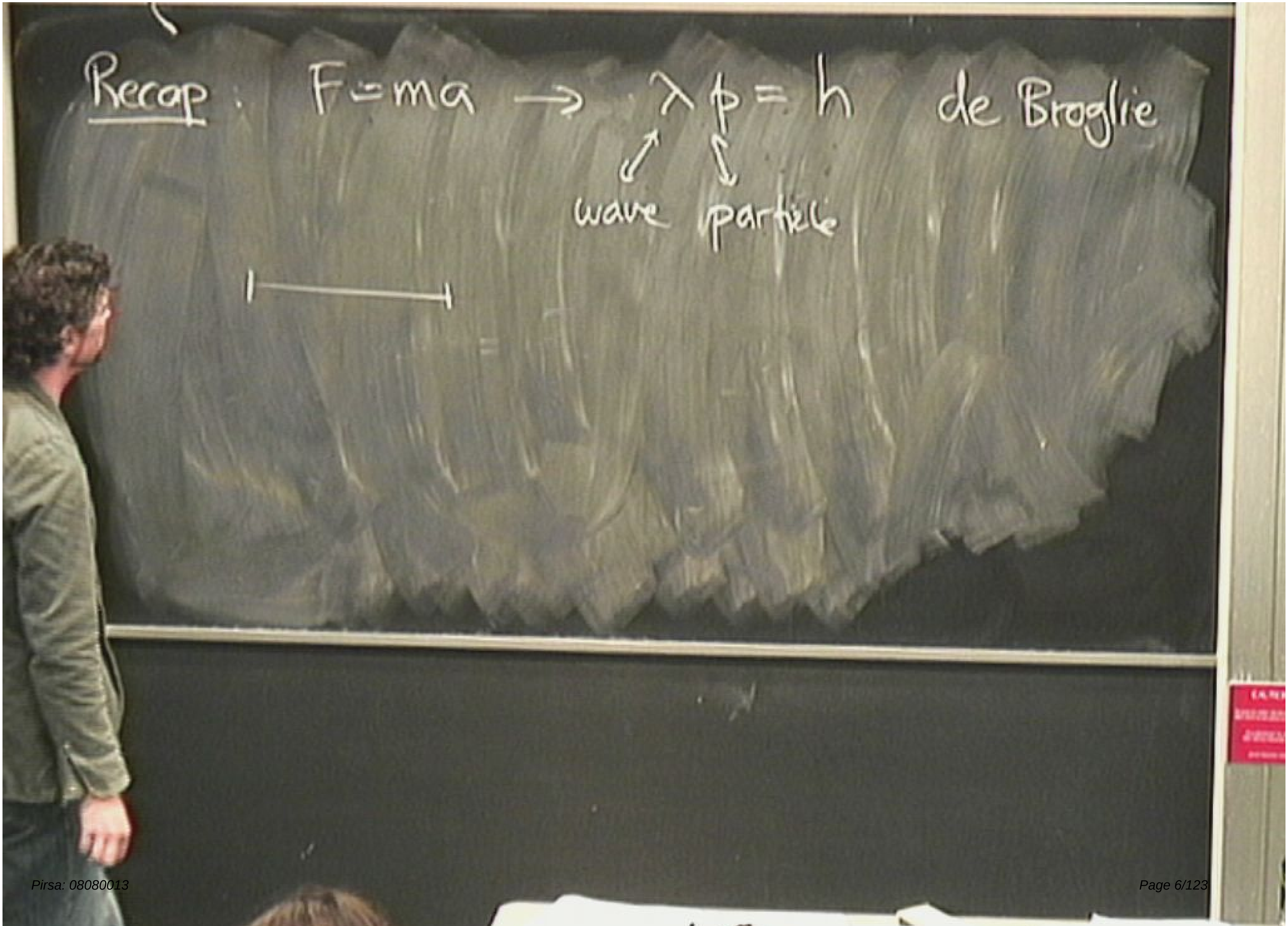
Abstract:

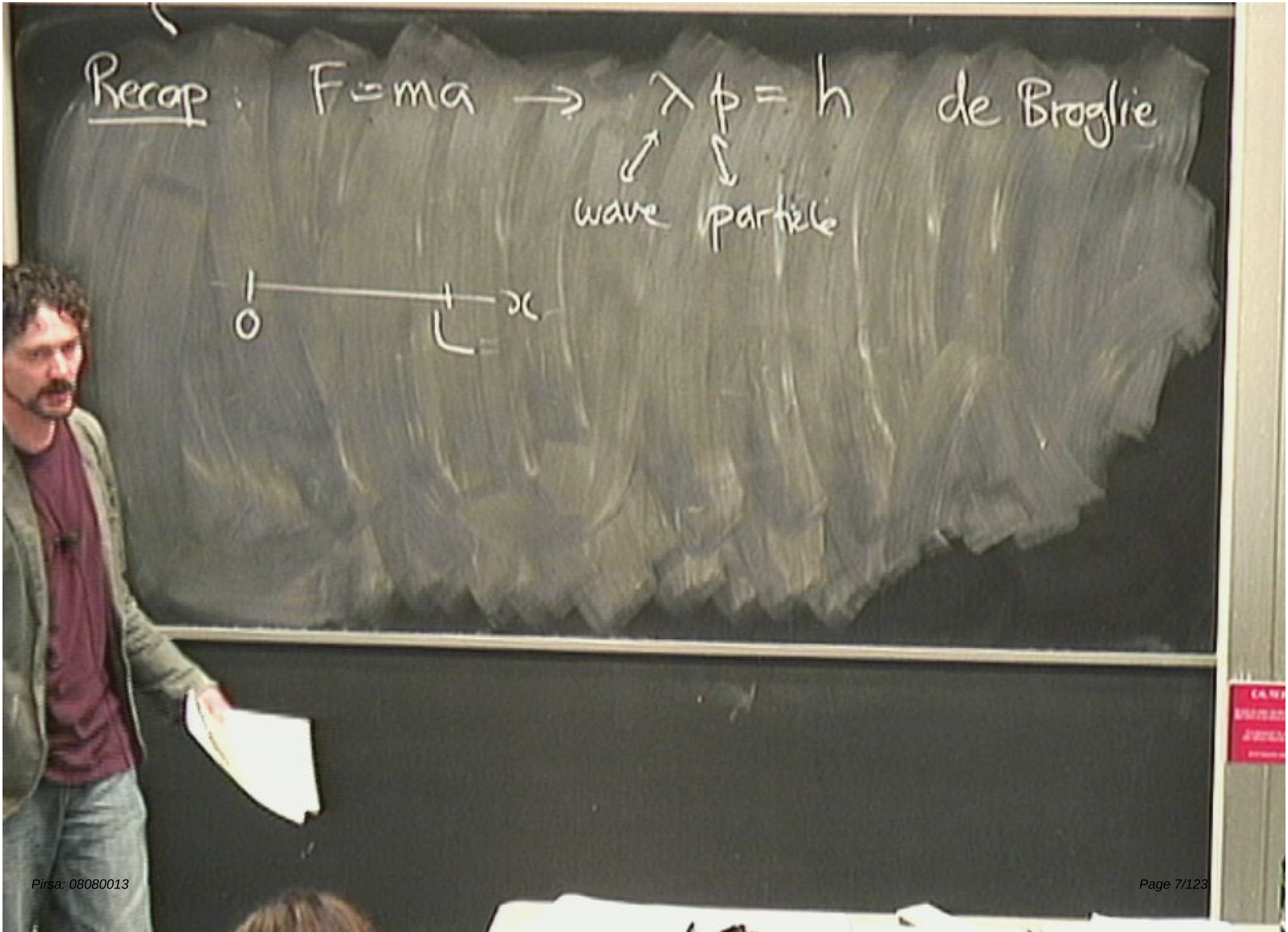

Recap : F = ma

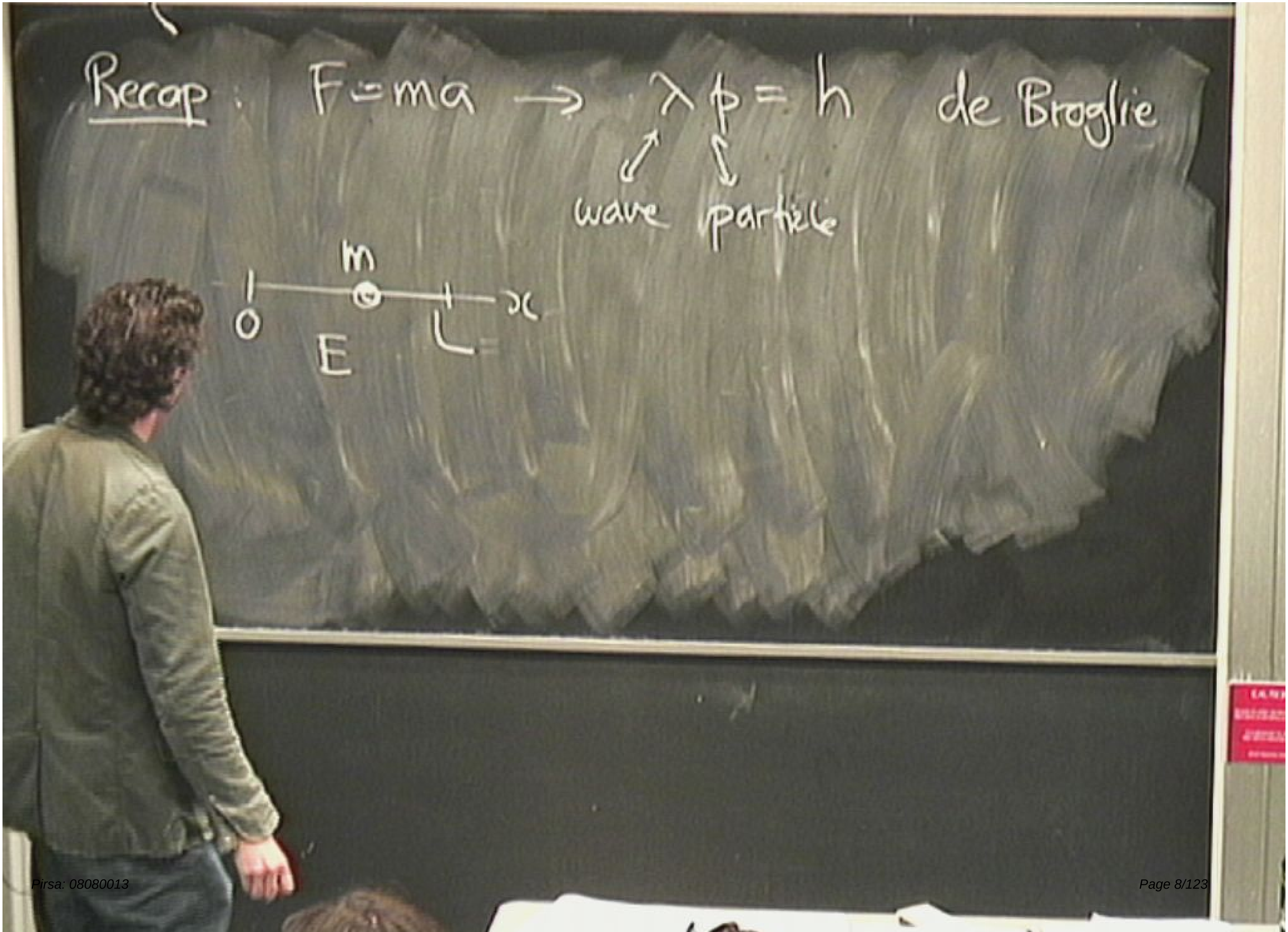

Recap: F=ma → λp=h

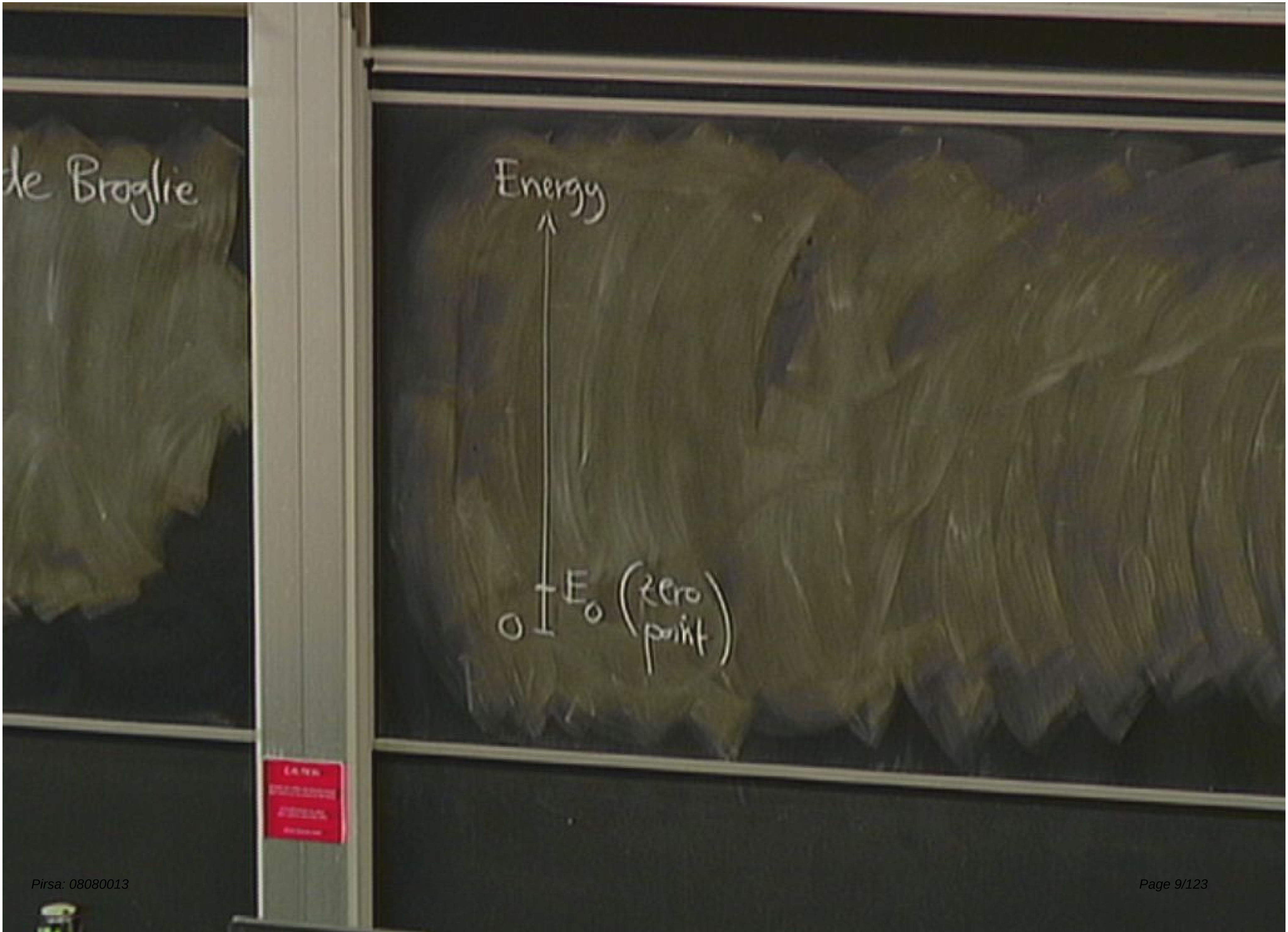

Recap: F=ma → λp = h de Broglie

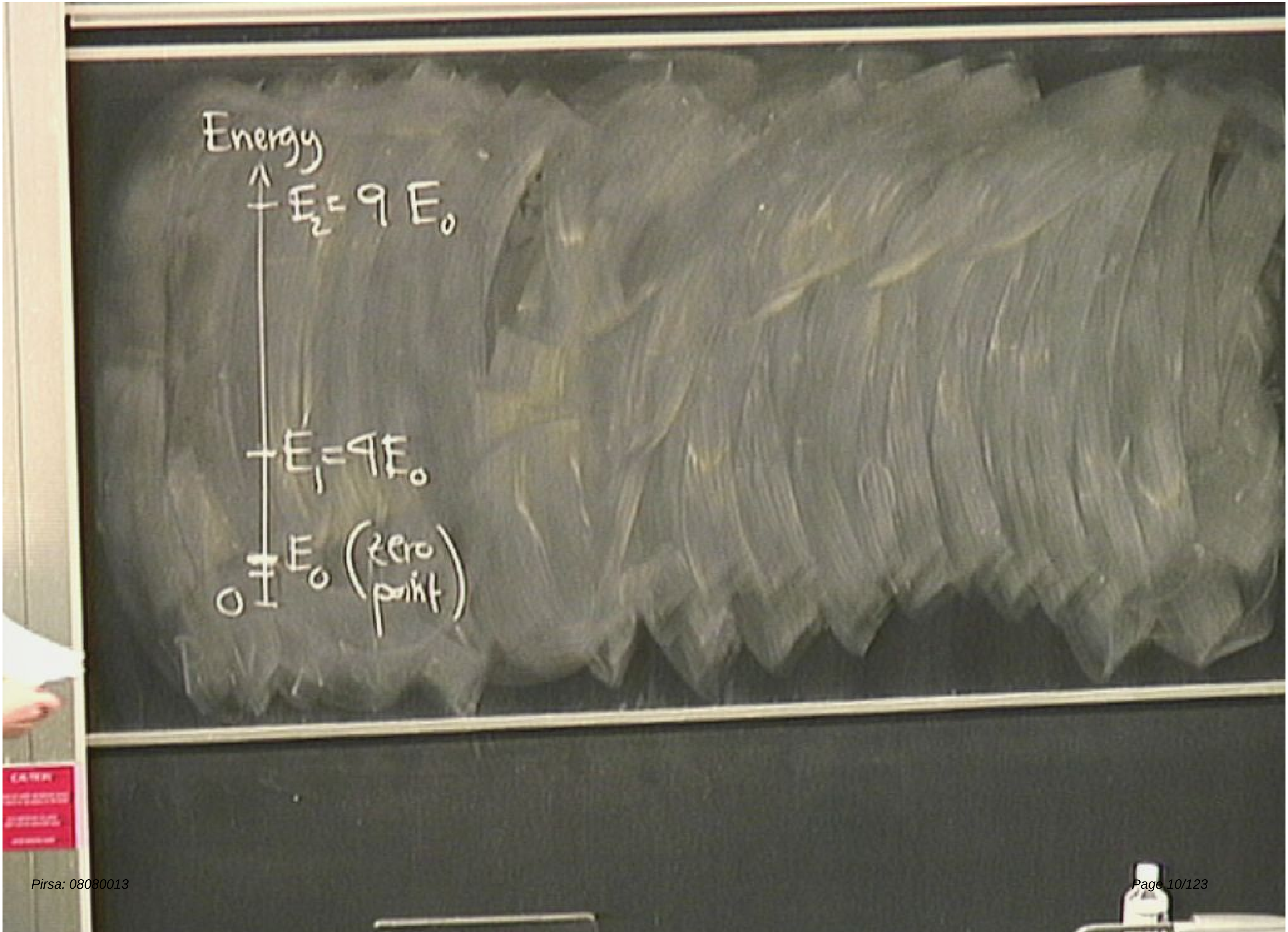

Recap : F=ma → λp = h de Broglie
wave
particle

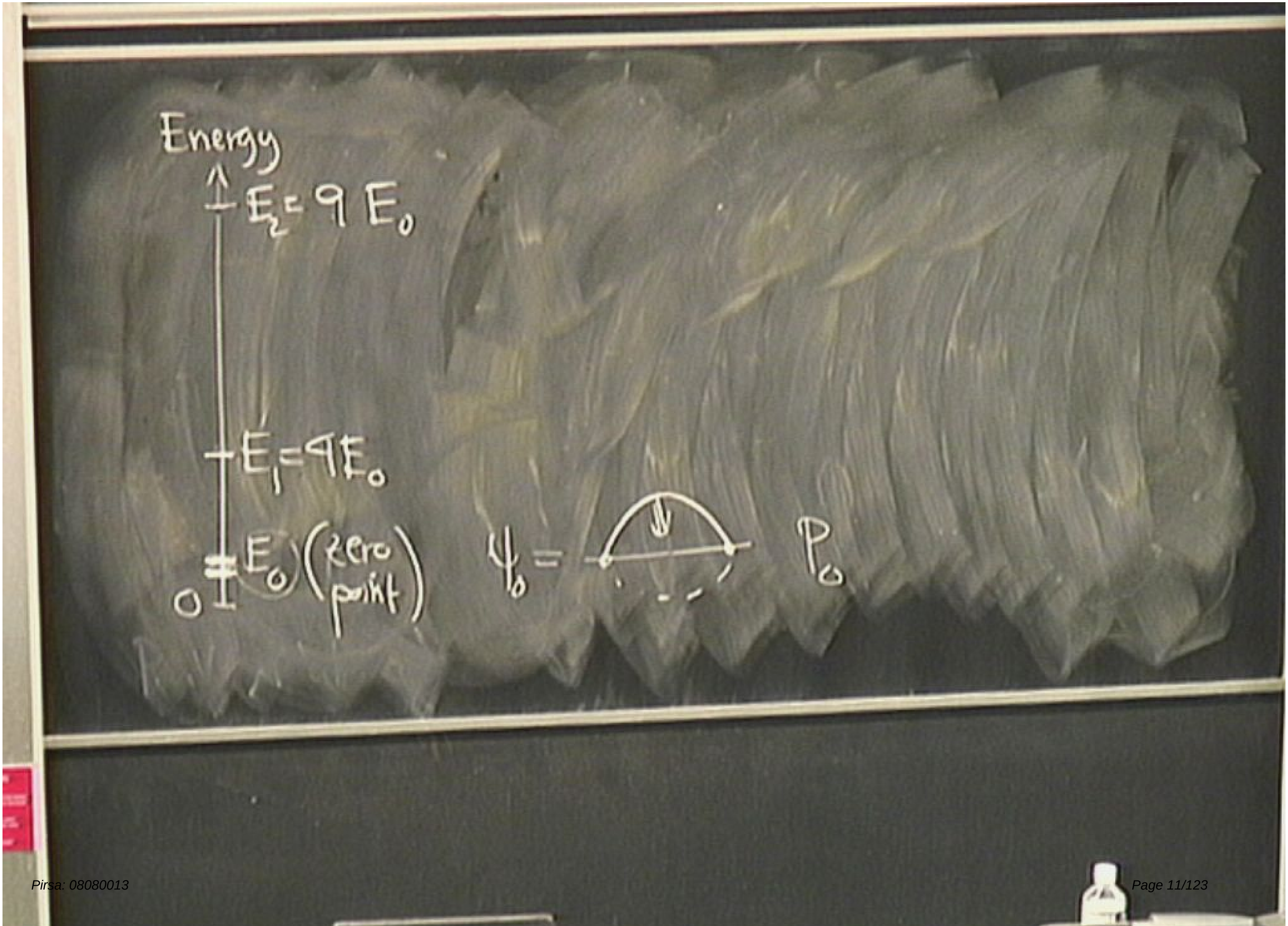

Recap: F = ma → λp = h de Broglie
wave
particle

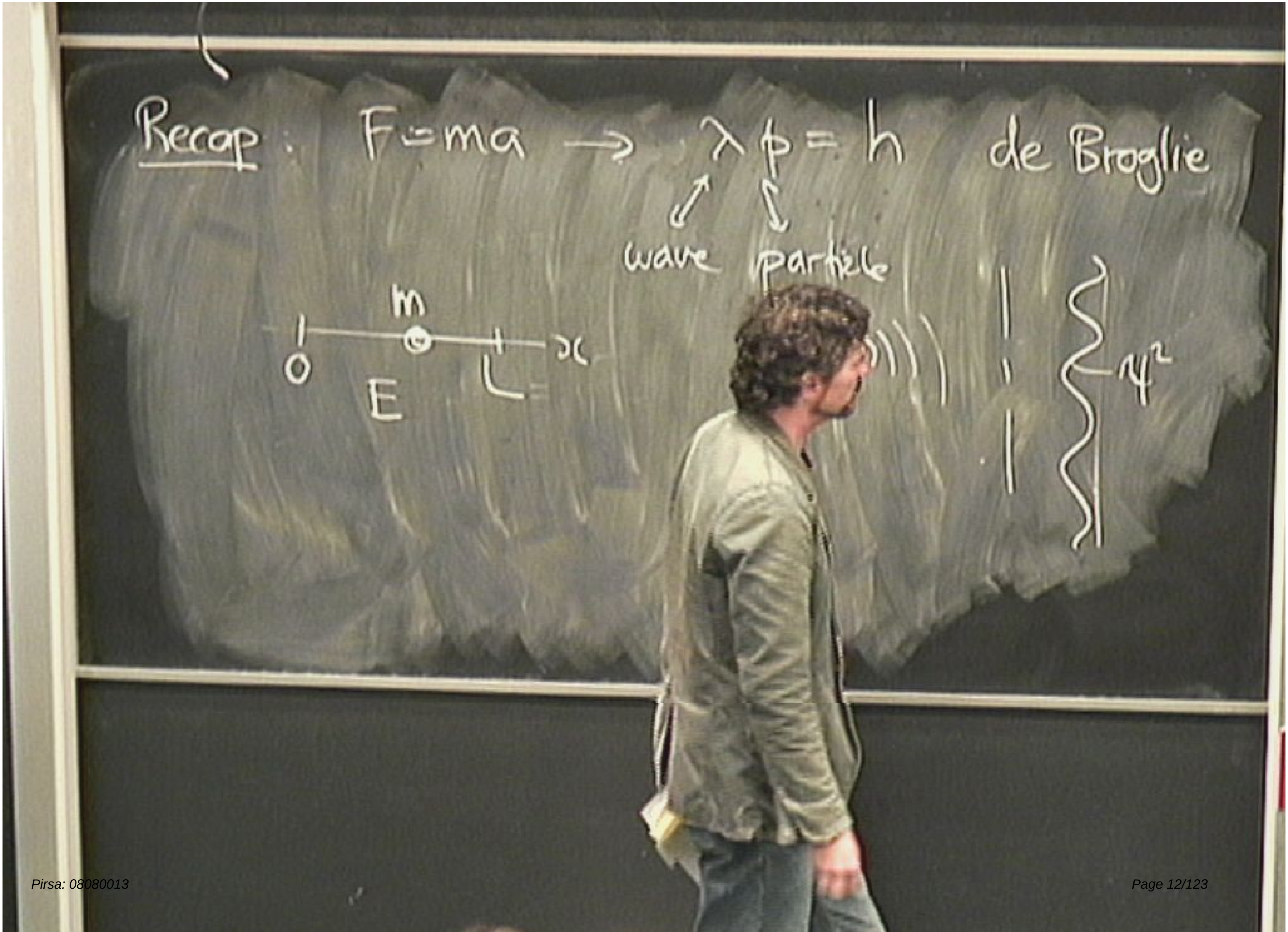

Recap: F = ma → λ p = h de Broglie
wave
particle
0
L
x

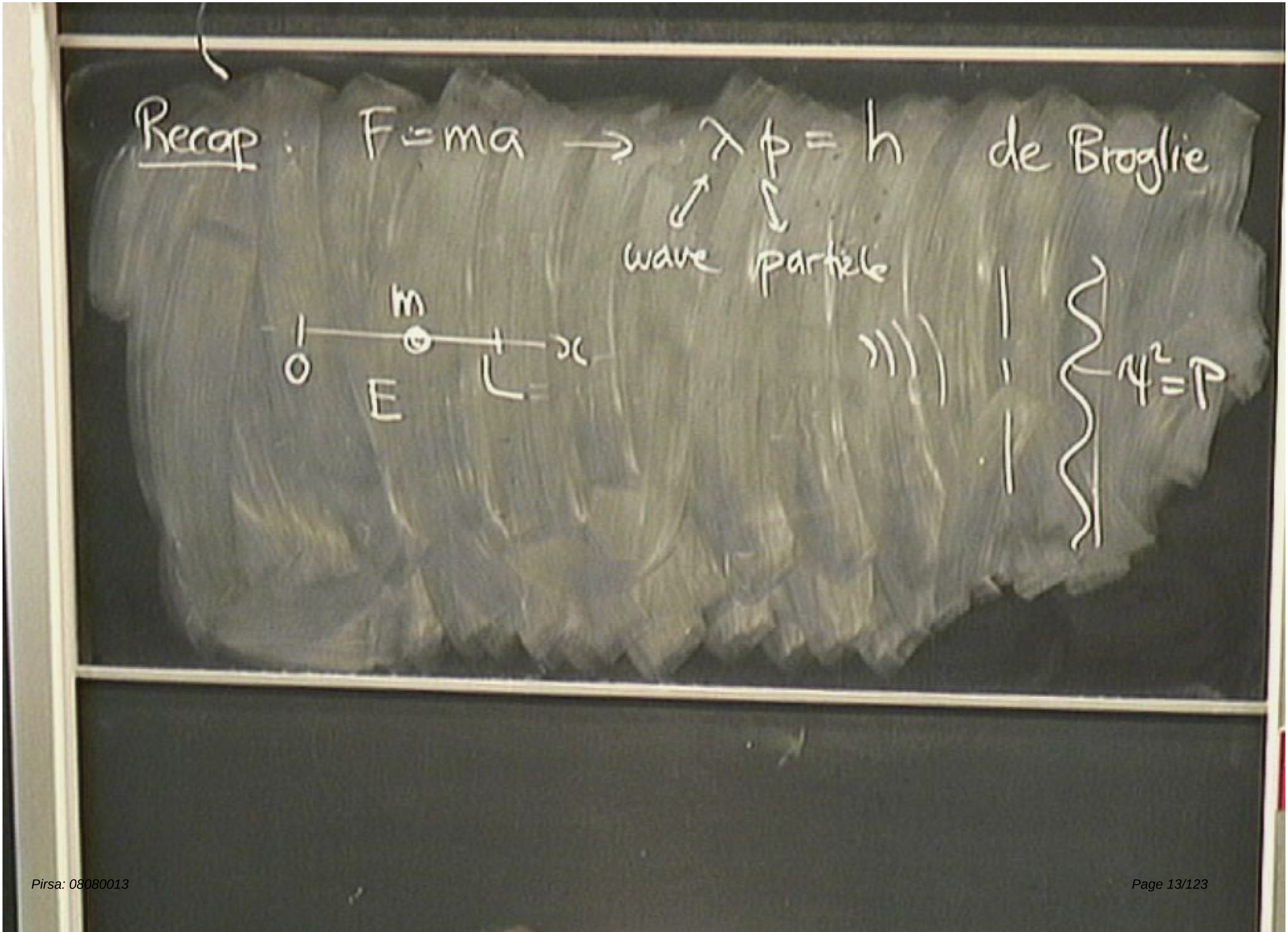

Recap: F=ma → λp = h de Broglie
wave particle
m
0
L
x
E

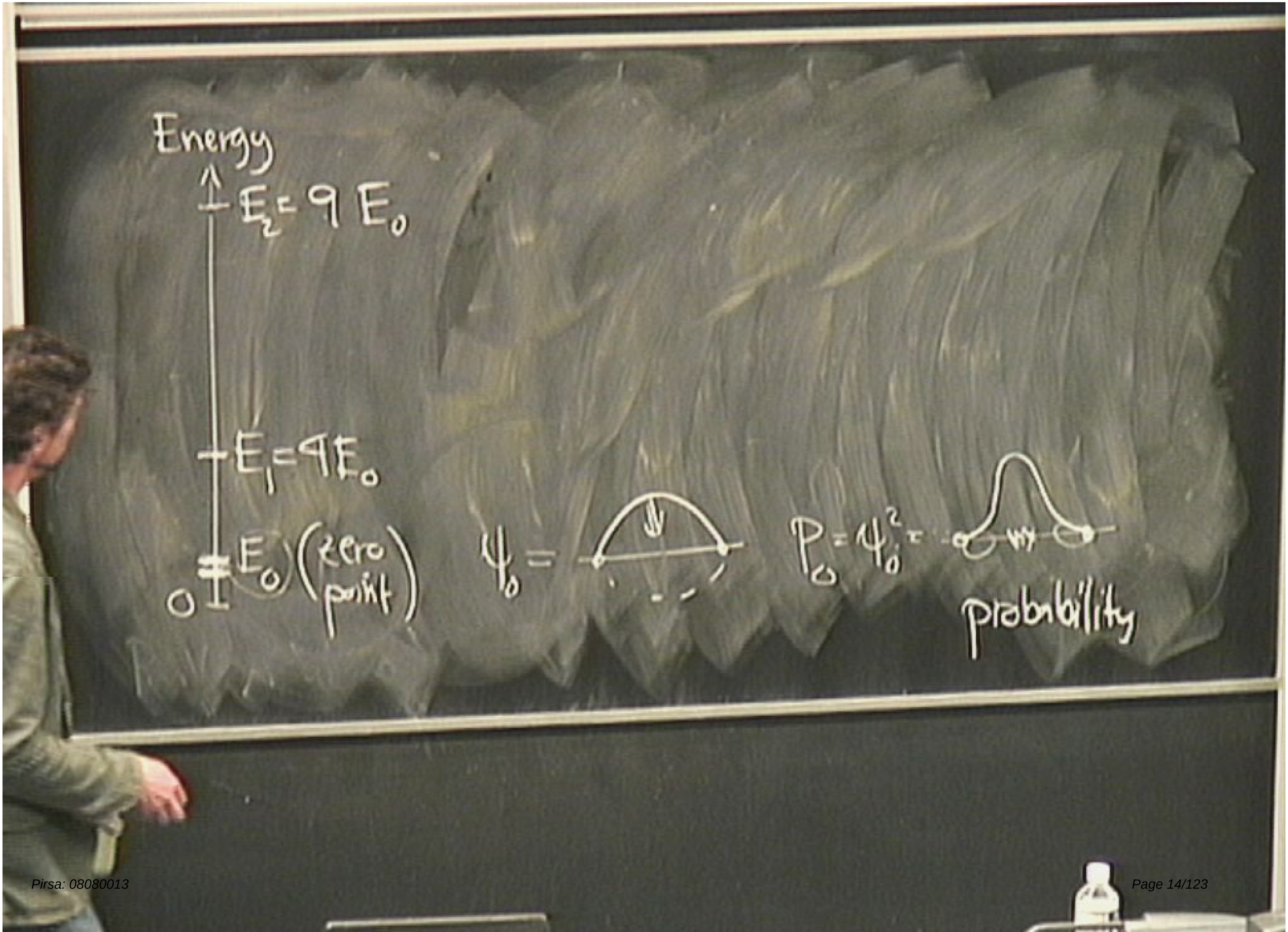

de Broglie
Energy
E_0 (zero point)
0

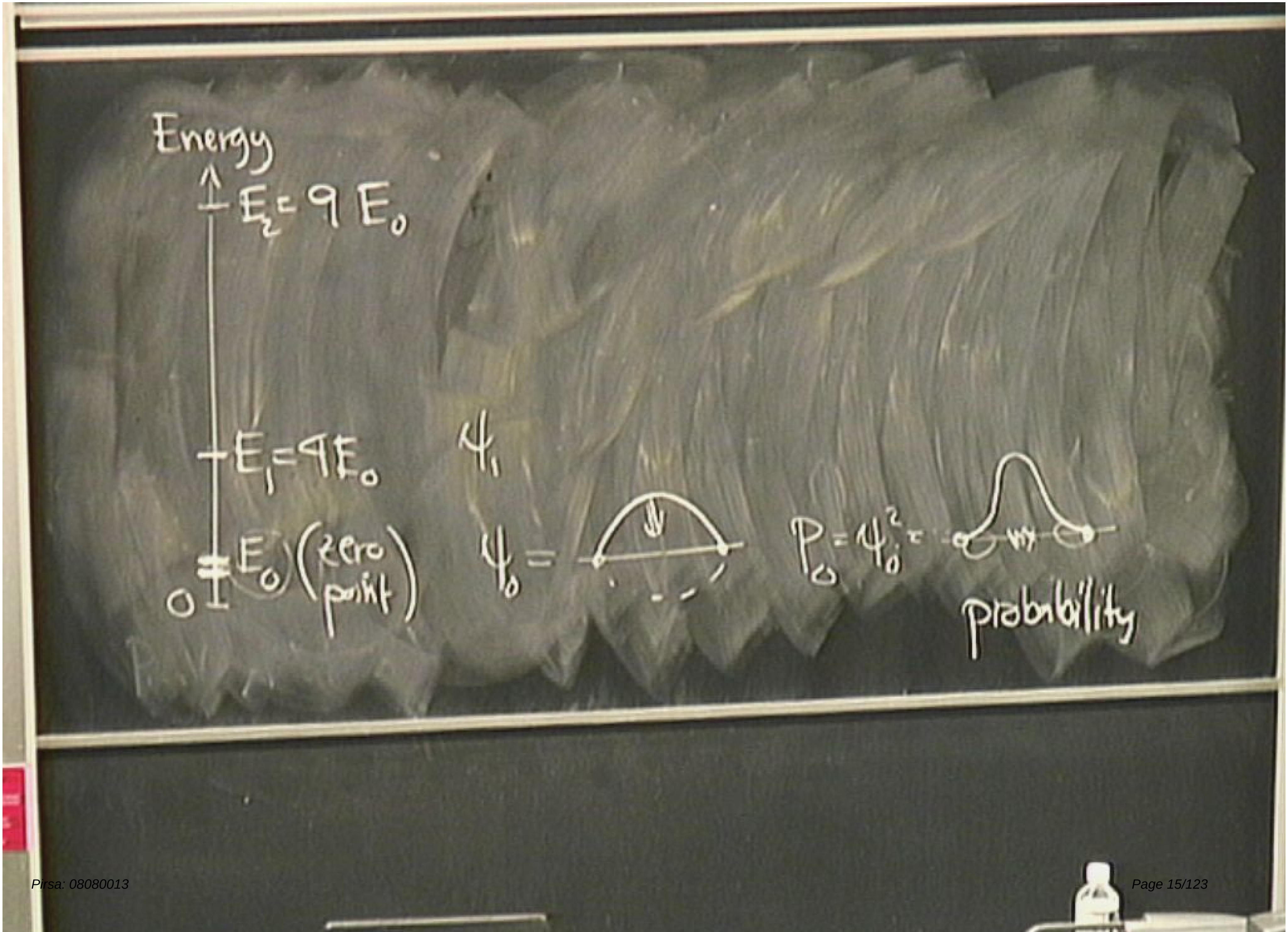

Energy
E2 = 9 E0
E1 = 4 E0
E0 (zero point)
0

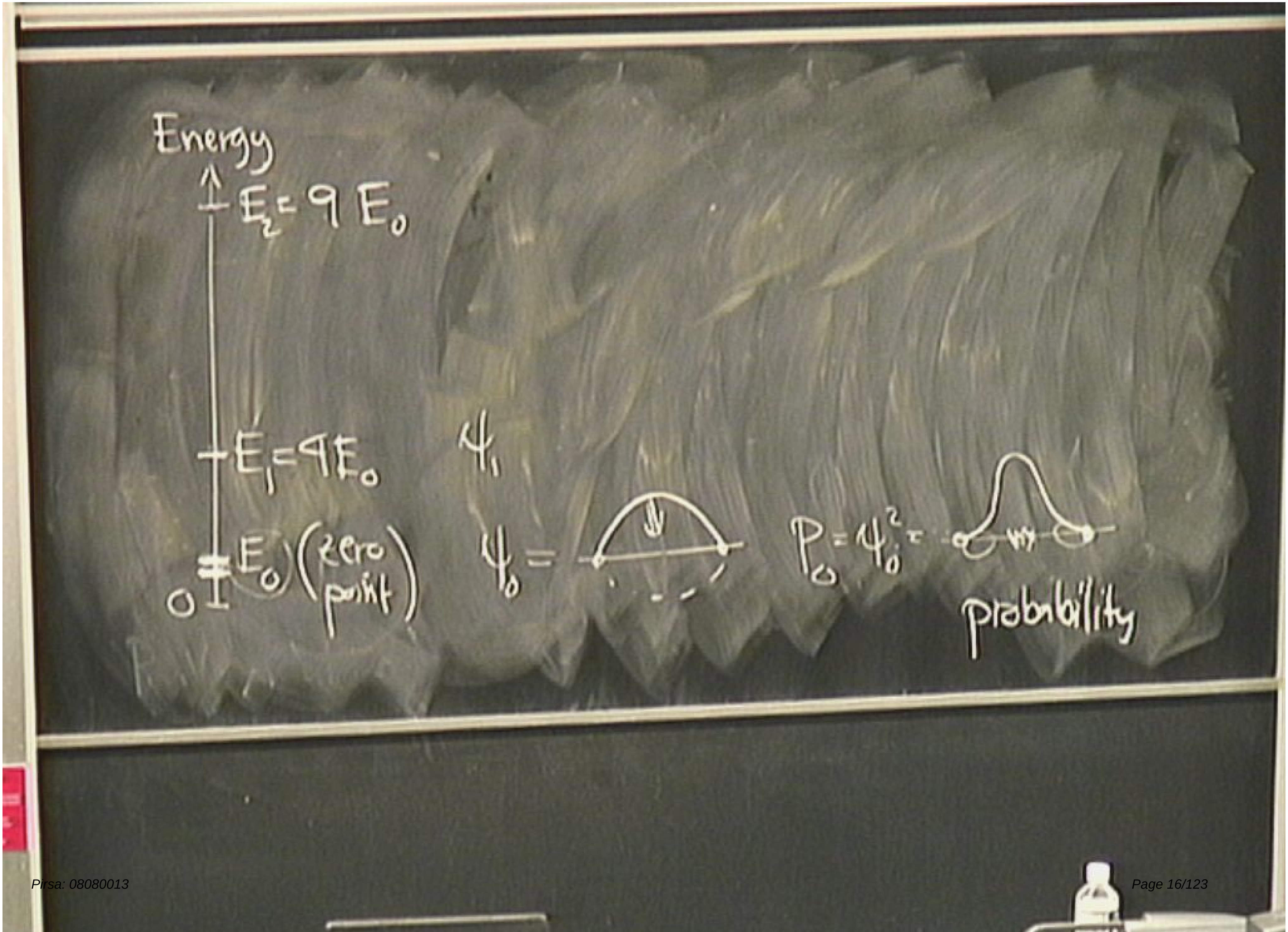

Energy
E2 = 9 E0
E1 = 4E0
E0 (zero point)
0
ψ0 =
P0

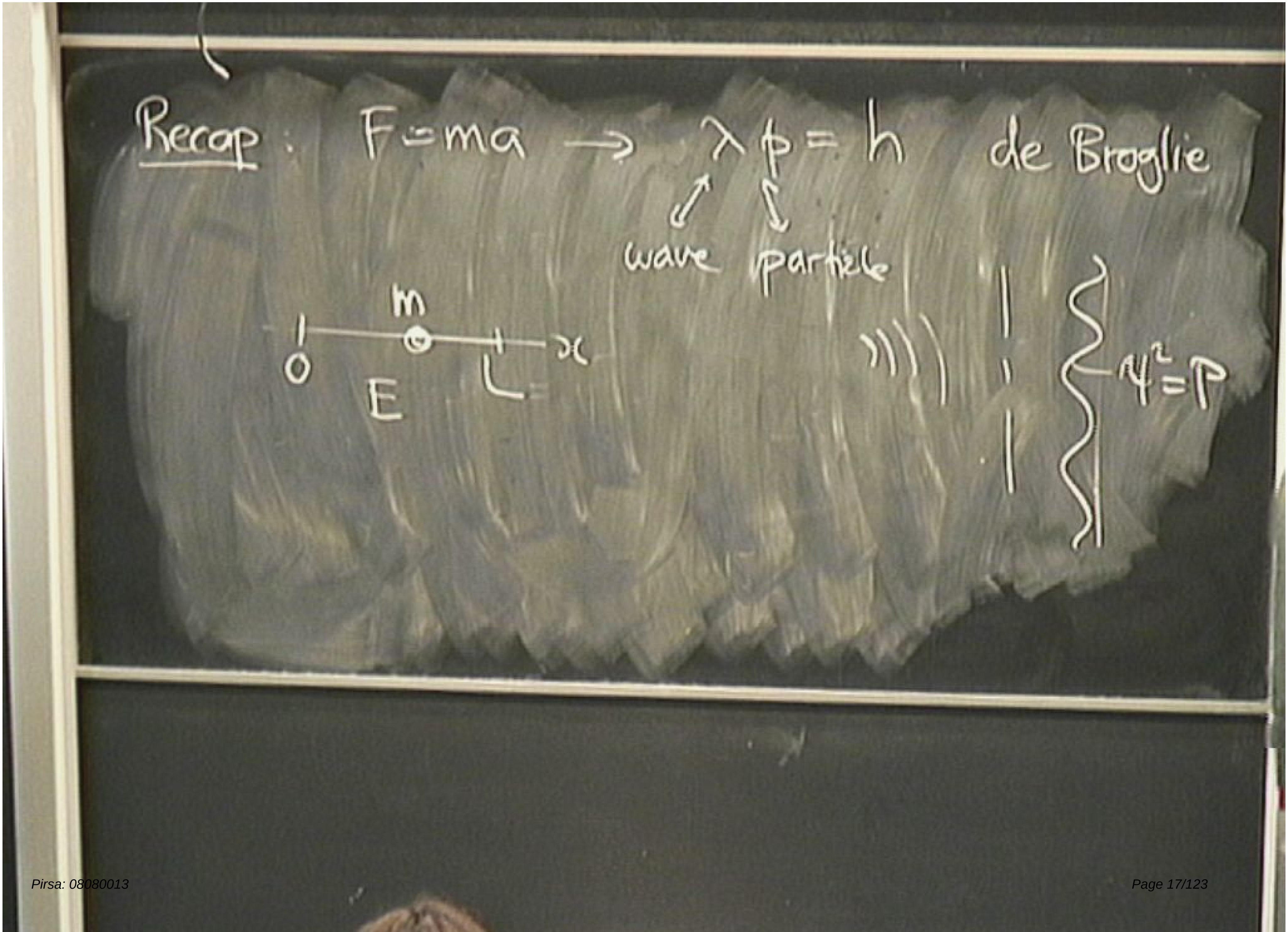

Recap: F=ma → λp = h de Broglie
wave
particle
m
0
L
x
E
ψ²

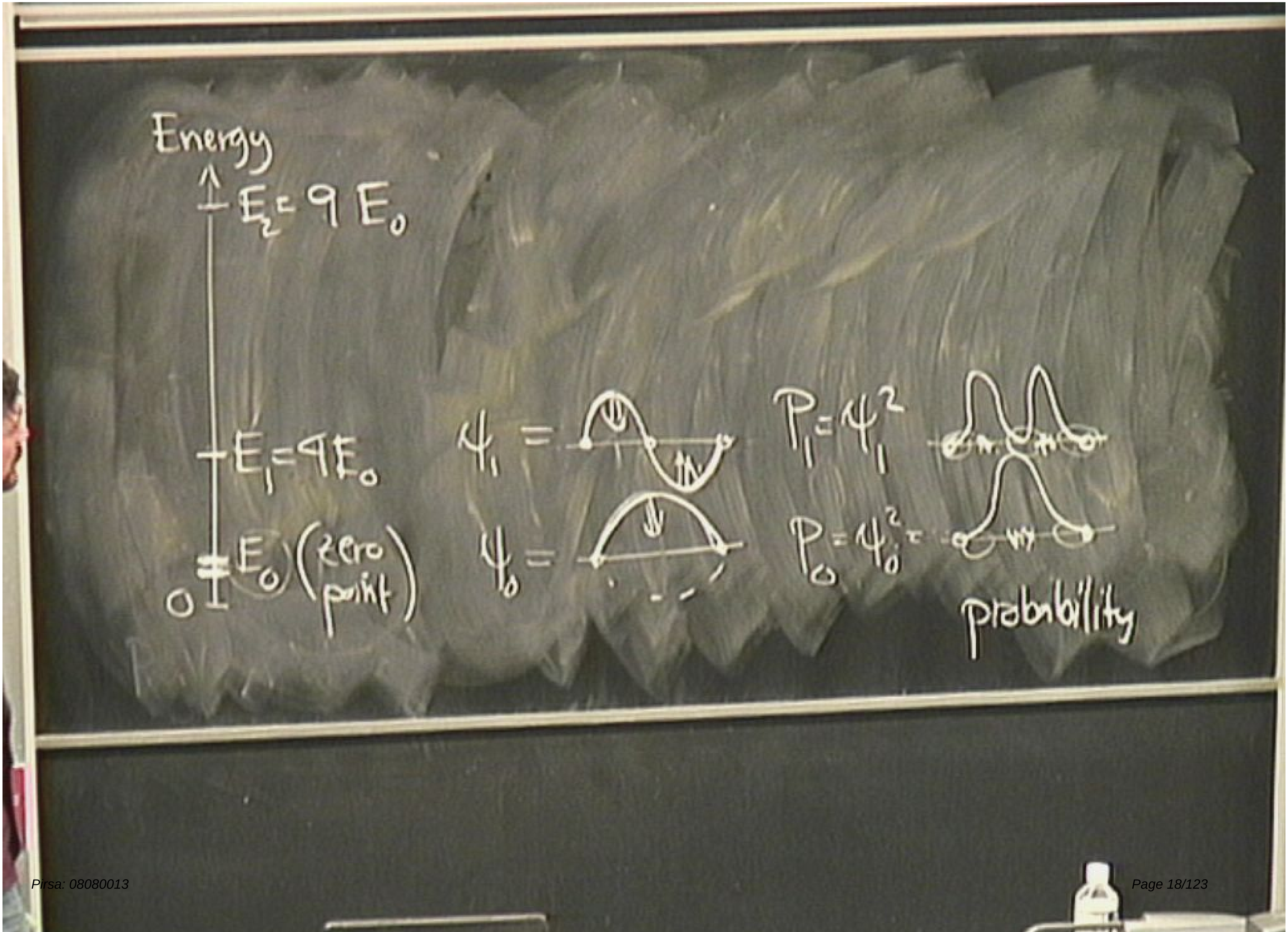

Recap: F=ma → λp = h de Broglie
wave particle
m
0 L x
E
$\psi^2 = P$

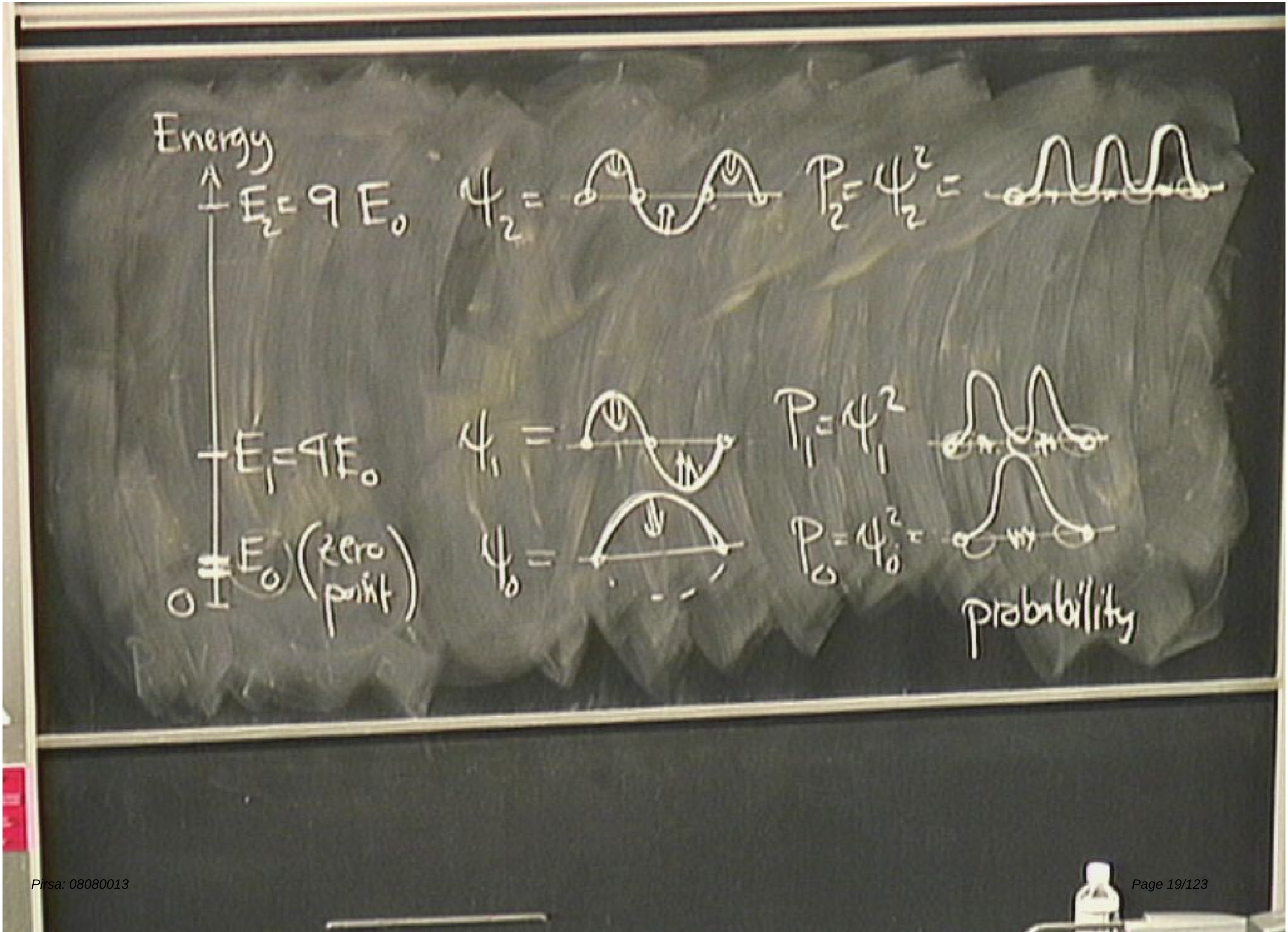

Energy
E2 = 9 E0
E1 = 4 E0
E0 (zero point)
0
ψ0 =
P0 = ψ0² =
probability

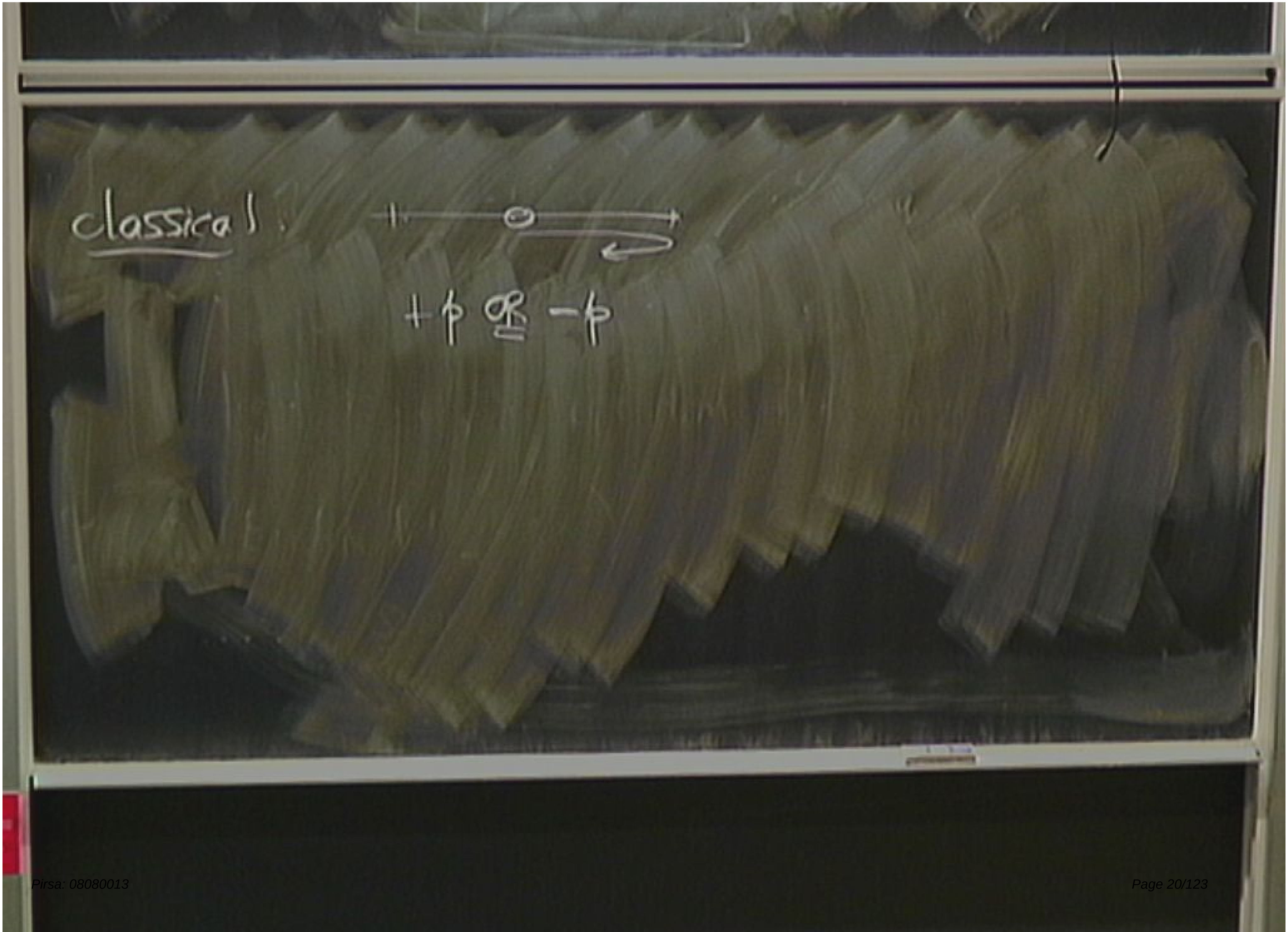

Energy
E2 = 9 E0
E1 = 4E0
E0 (zero point)
0
ψ1
ψ0 =
P0 = ψ0² =
probability

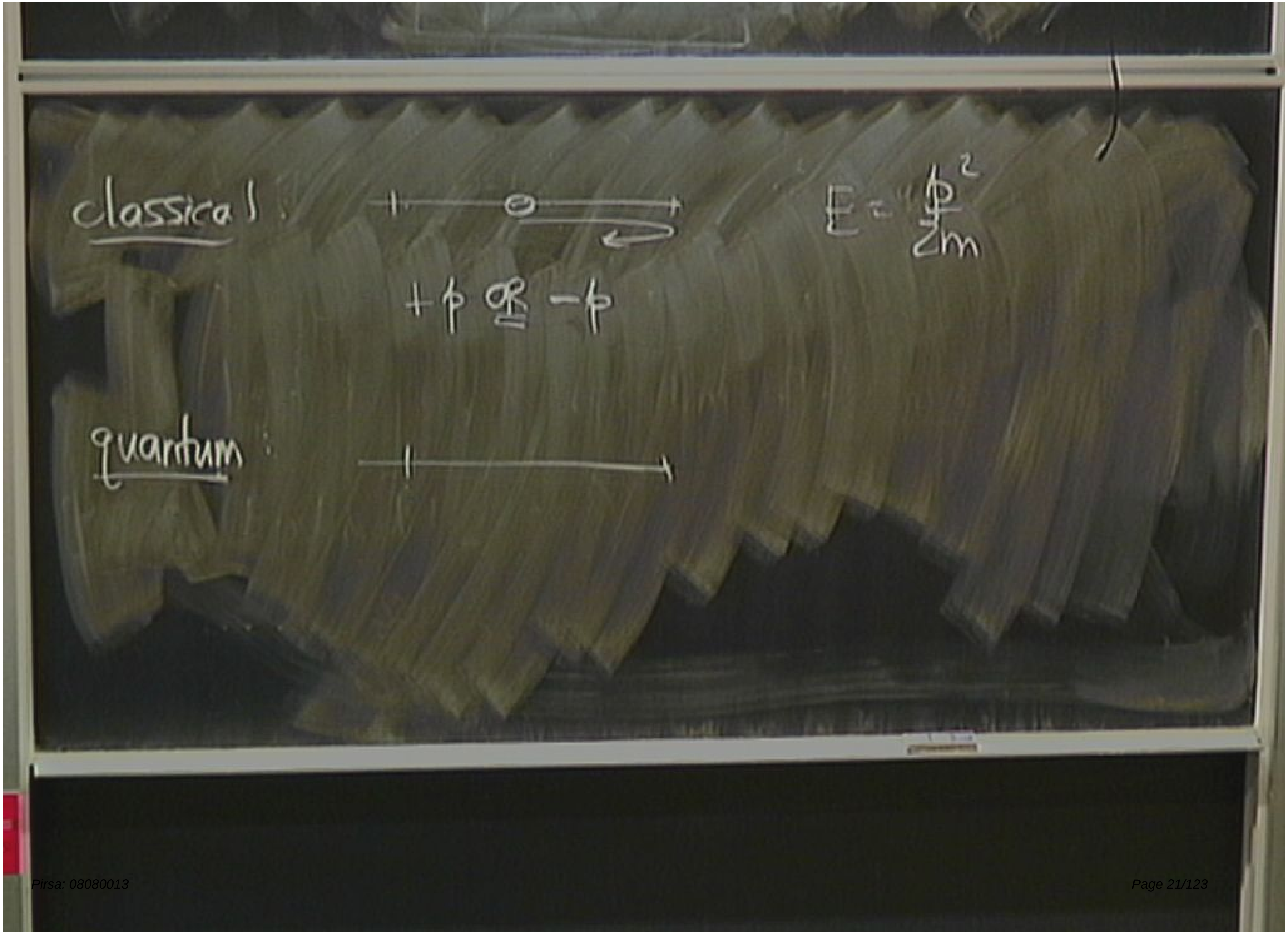

Energy
E2 = 9 E0
E1 = 4 E0
E0 (zero point)
0
ψ1
ψ0 =
P0 = ψ0² =
probability

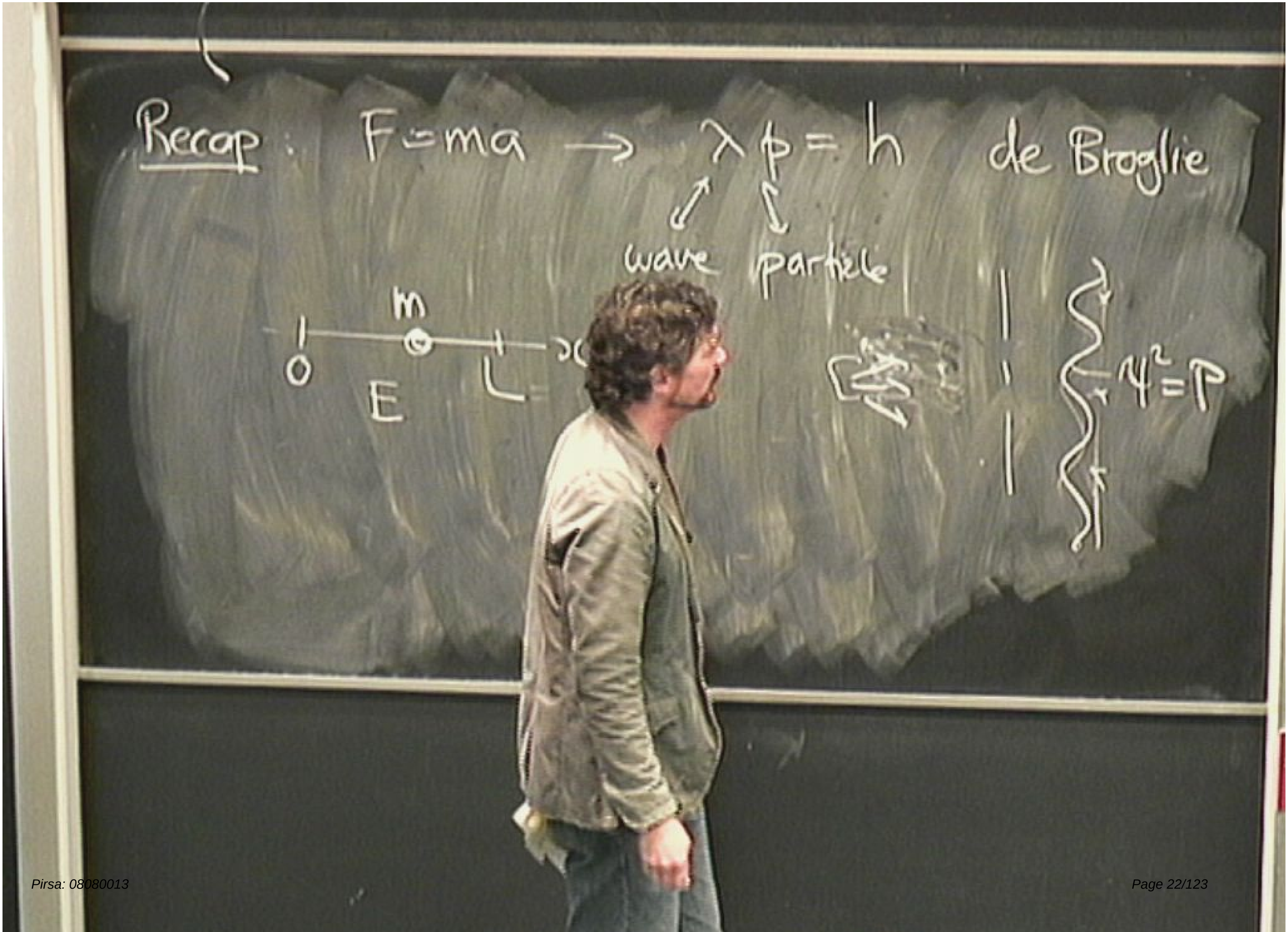

Recap: F=ma → λp = h de Broglie
wave particle
m
0
E
L
x
ψ²=P

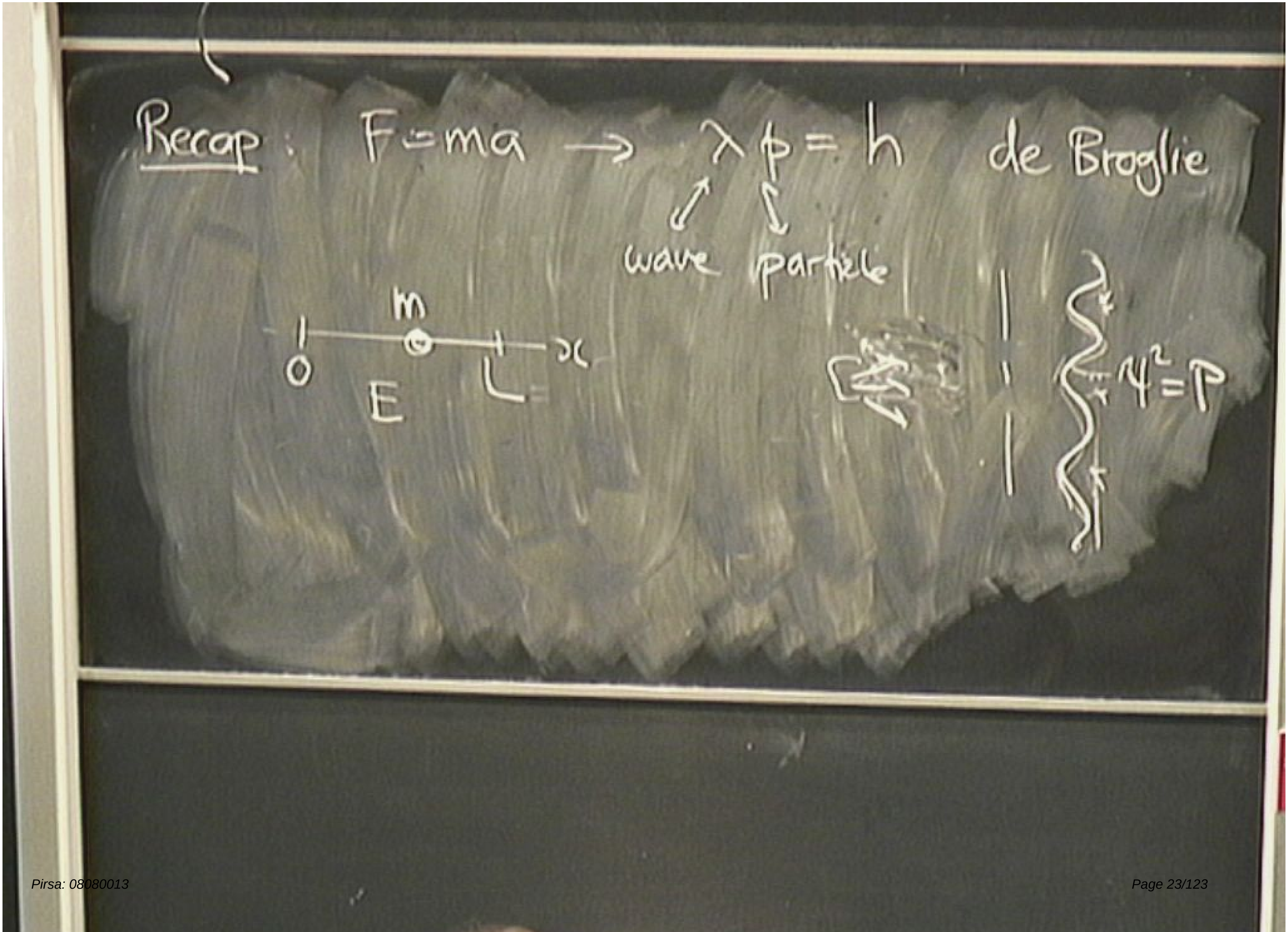

Energy
E2 = 9 E0
E1 = 4E0
E0 (zero point)
0
ψ1 =
ψ0 =
P1 = ψ1²
P0 = ψ0² =
probability

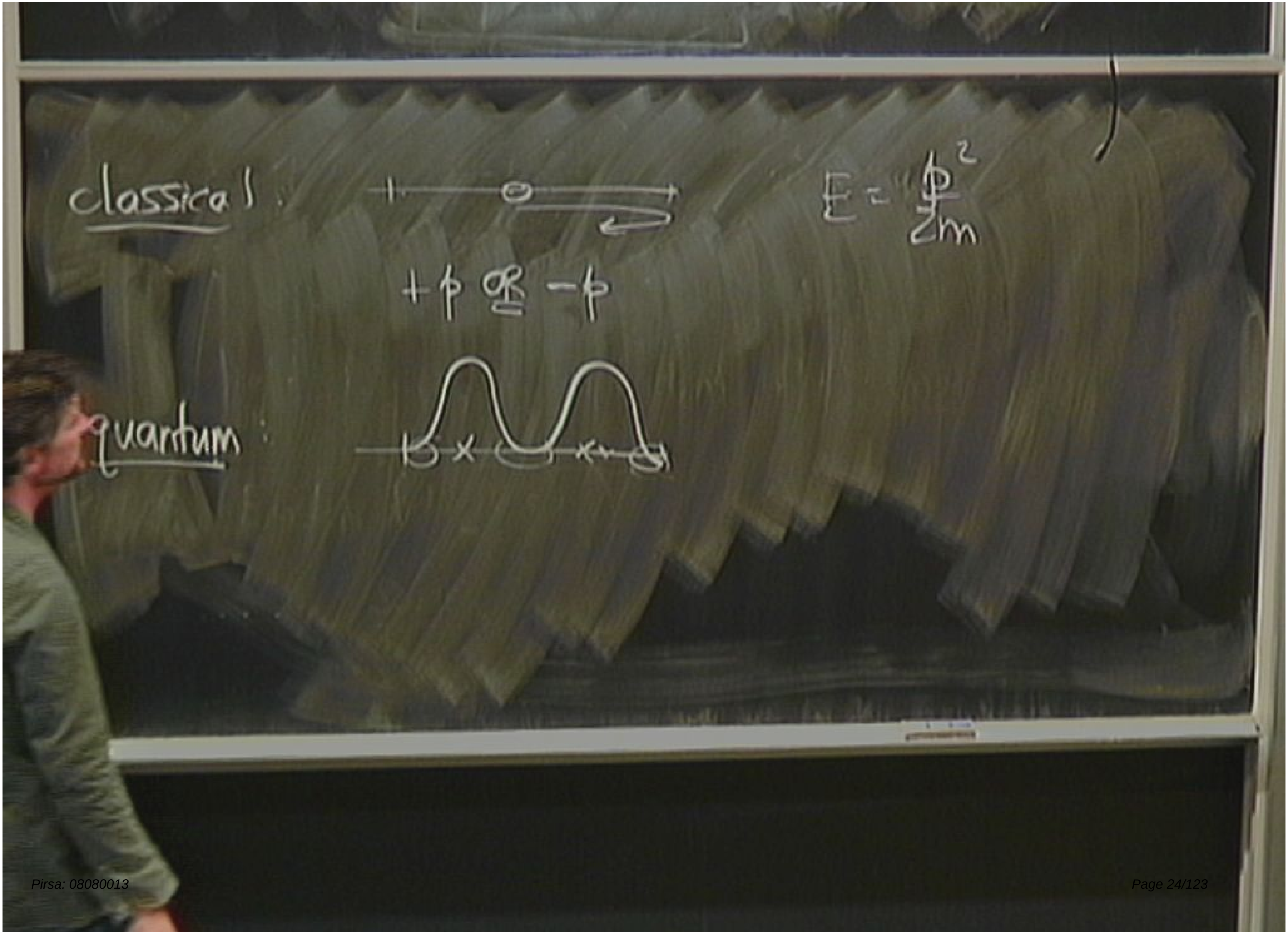

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2² =
E1 = 4E0
ψ1 =
P1 = ψ1²
E0 (zero point)
0
ψ0 =
P0 = ψ0² =
probability

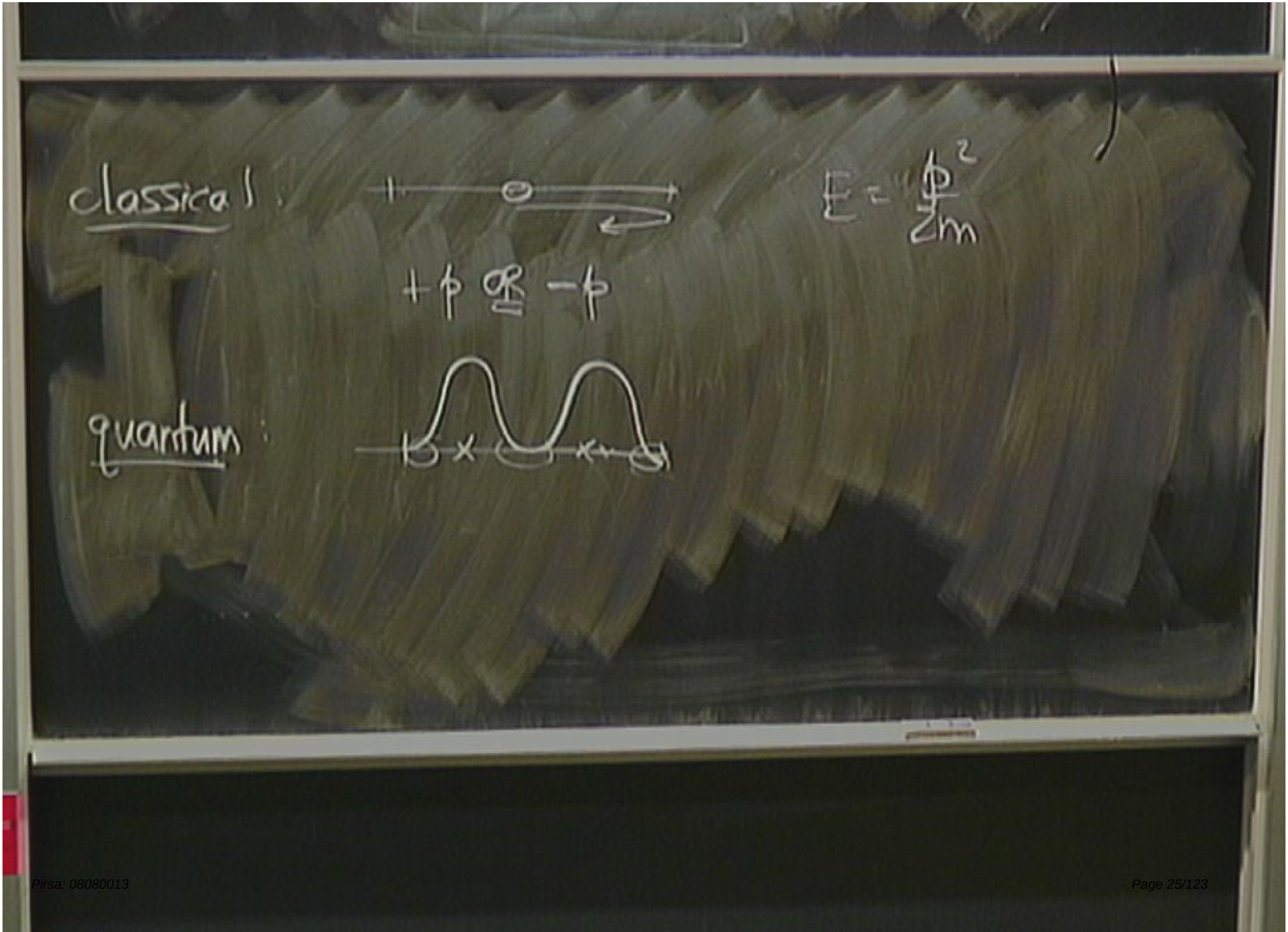

classical :
+p OR -p

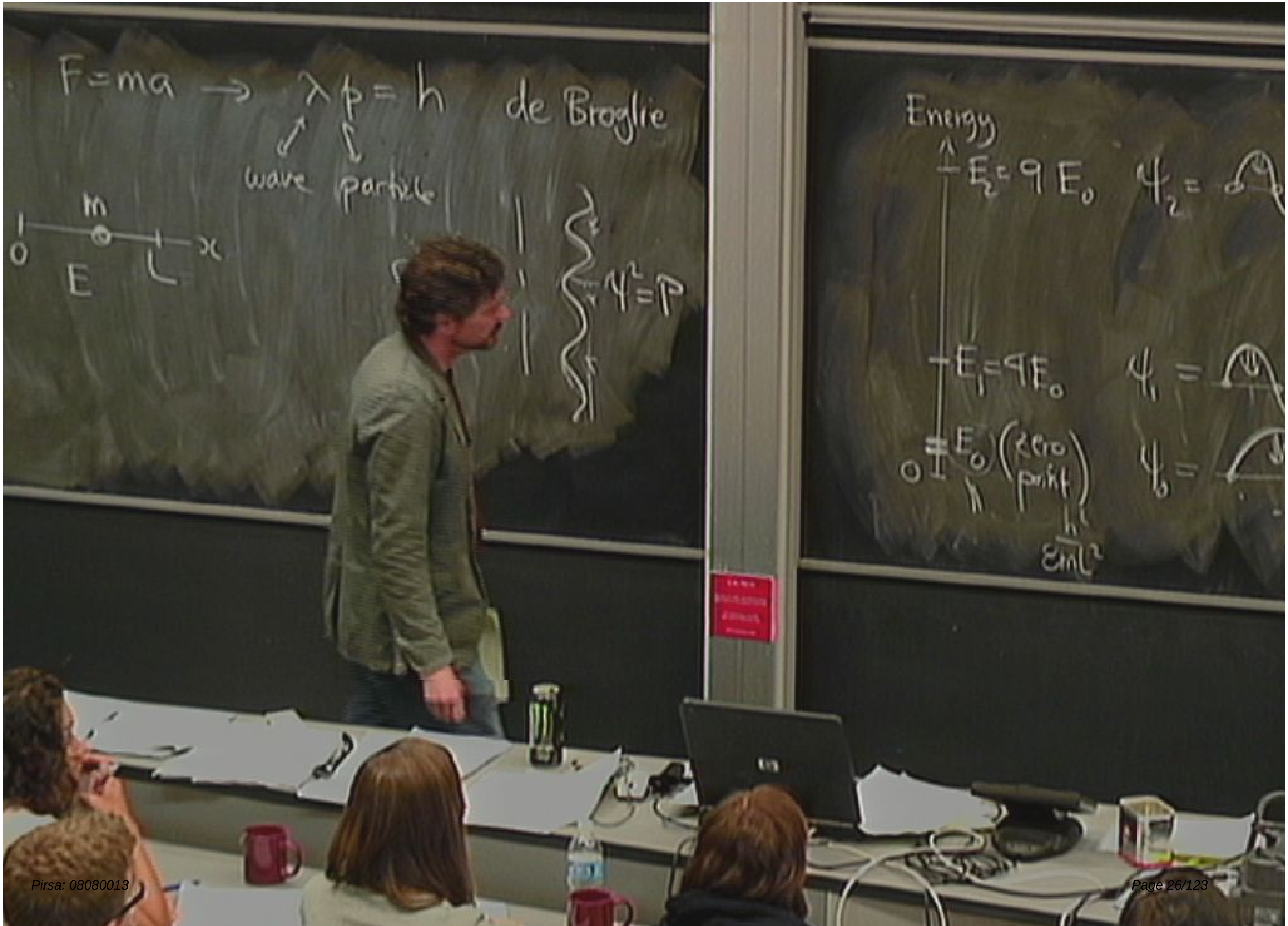

classical :
E = p²/2m
+p OR −p
quantum :

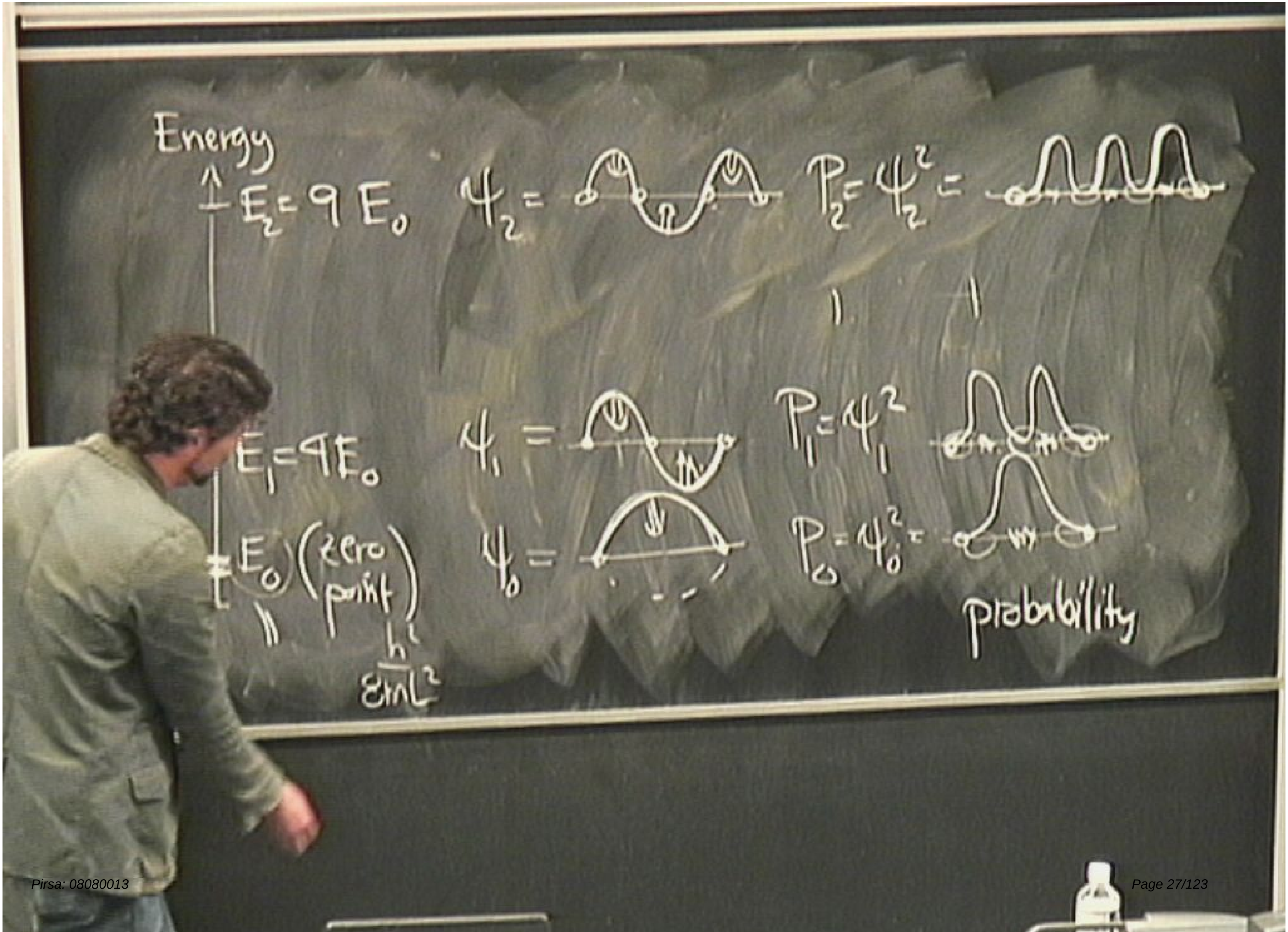

Recap: F = ma → λp = h de Broglie
wave
particle
m
0
E
L
ψ² = P


Recap: F=ma → λp = h de Broglie
wave
particle
m
0
x
E
L
ψ² = P

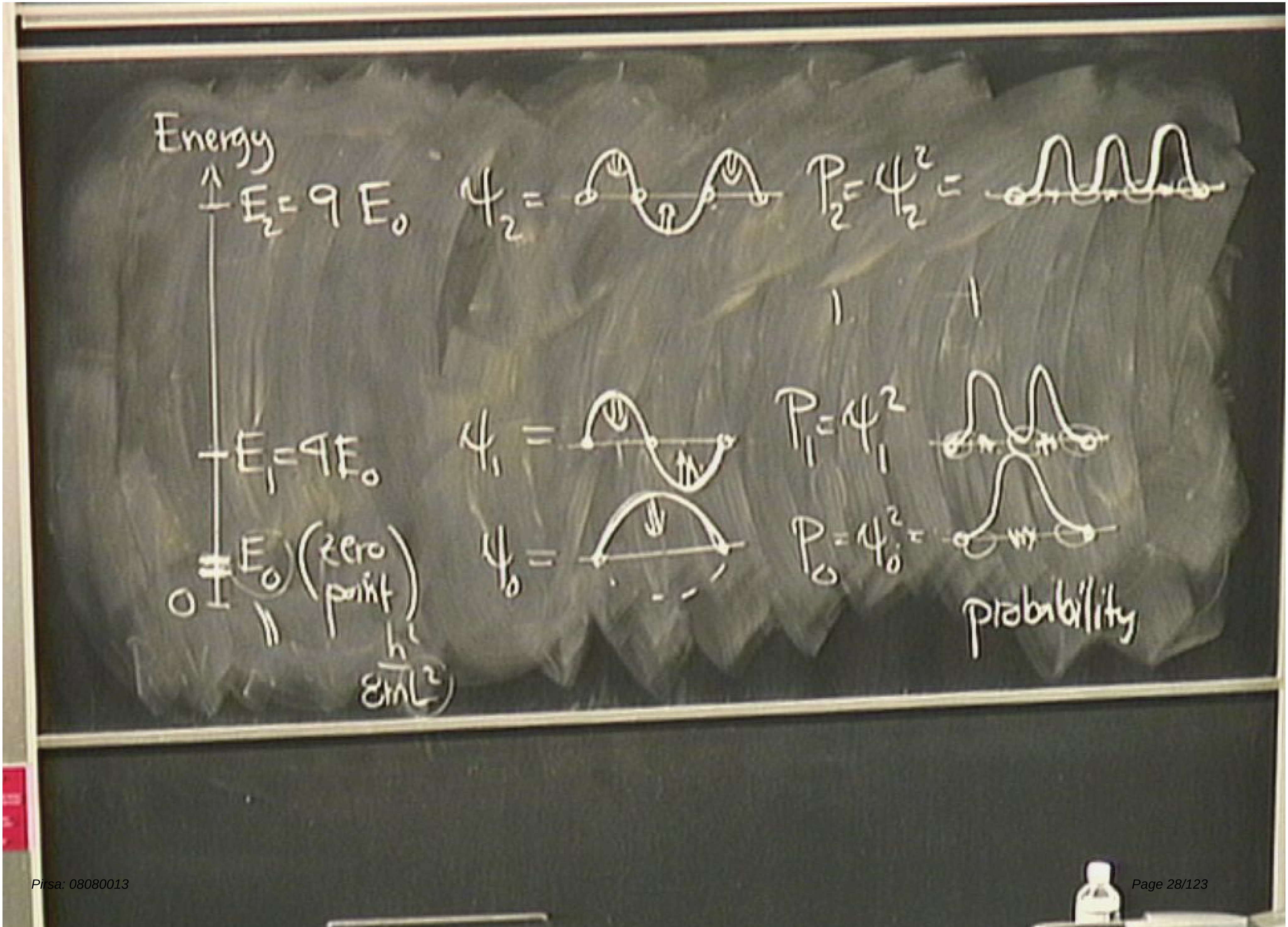

classical :
+p OR -p
E = p^2/2m
quantum :

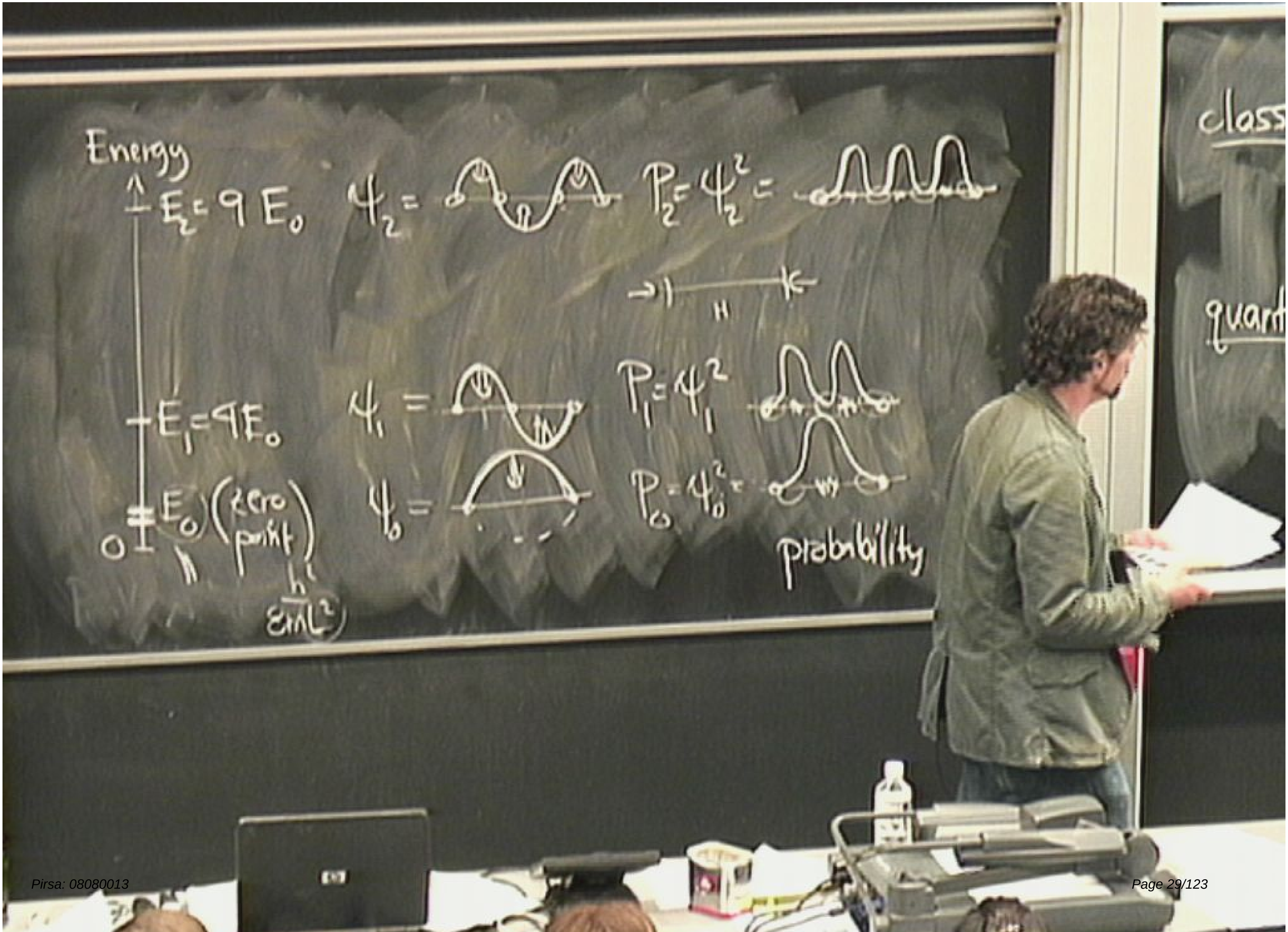

classical
+p or −p
E = p²/2m
quantum


F=ma → λp=h
de Broglie
wave
particle
m
0
x
E
L
ψ² = P
Energy
E₂ = 9 E₀
ψ₂ =
E₁ = 4E₀
ψ₁ =
E₀ (zero point)
ψ₀ =
0
h²/8mL²

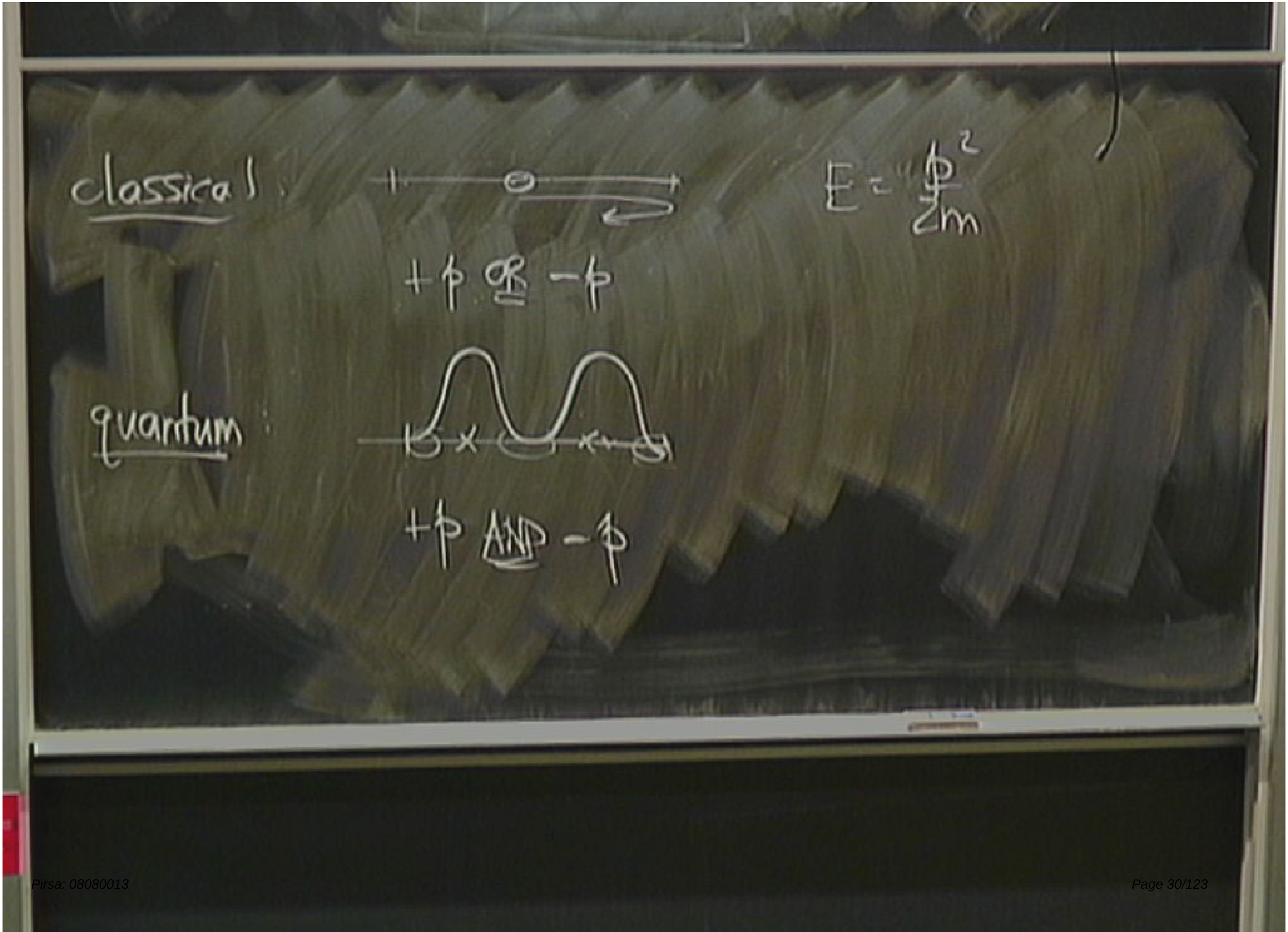


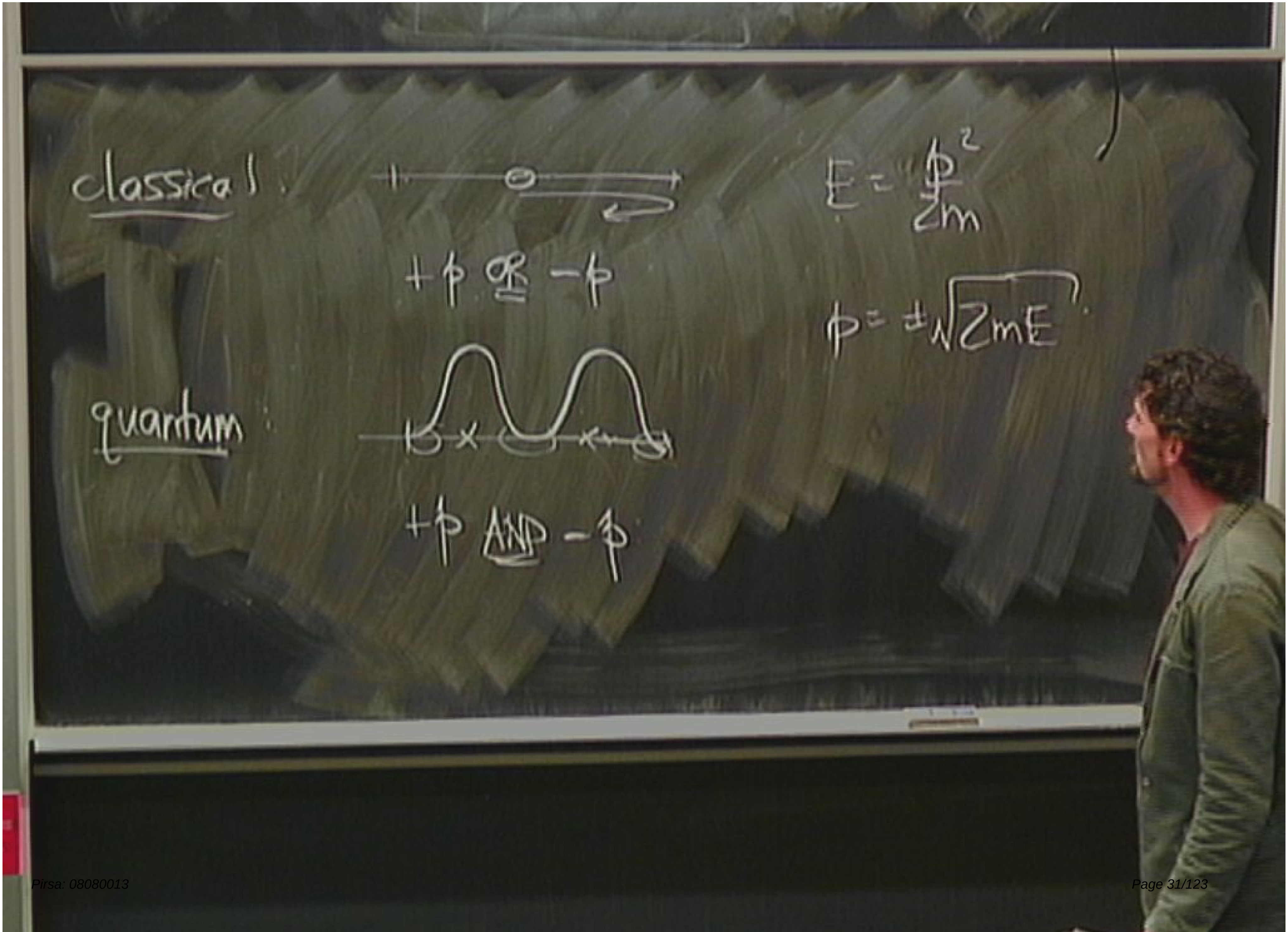
Energy
E2 = 9 E0
ψ2 =
P2 = ψ2^2 =
E1 = 4E0
ψ1 =
P1 = ψ1^2
E0 (zero point)
ψ0 =
P0 = ψ0^2 =
probability
h^2 / 8mL^2

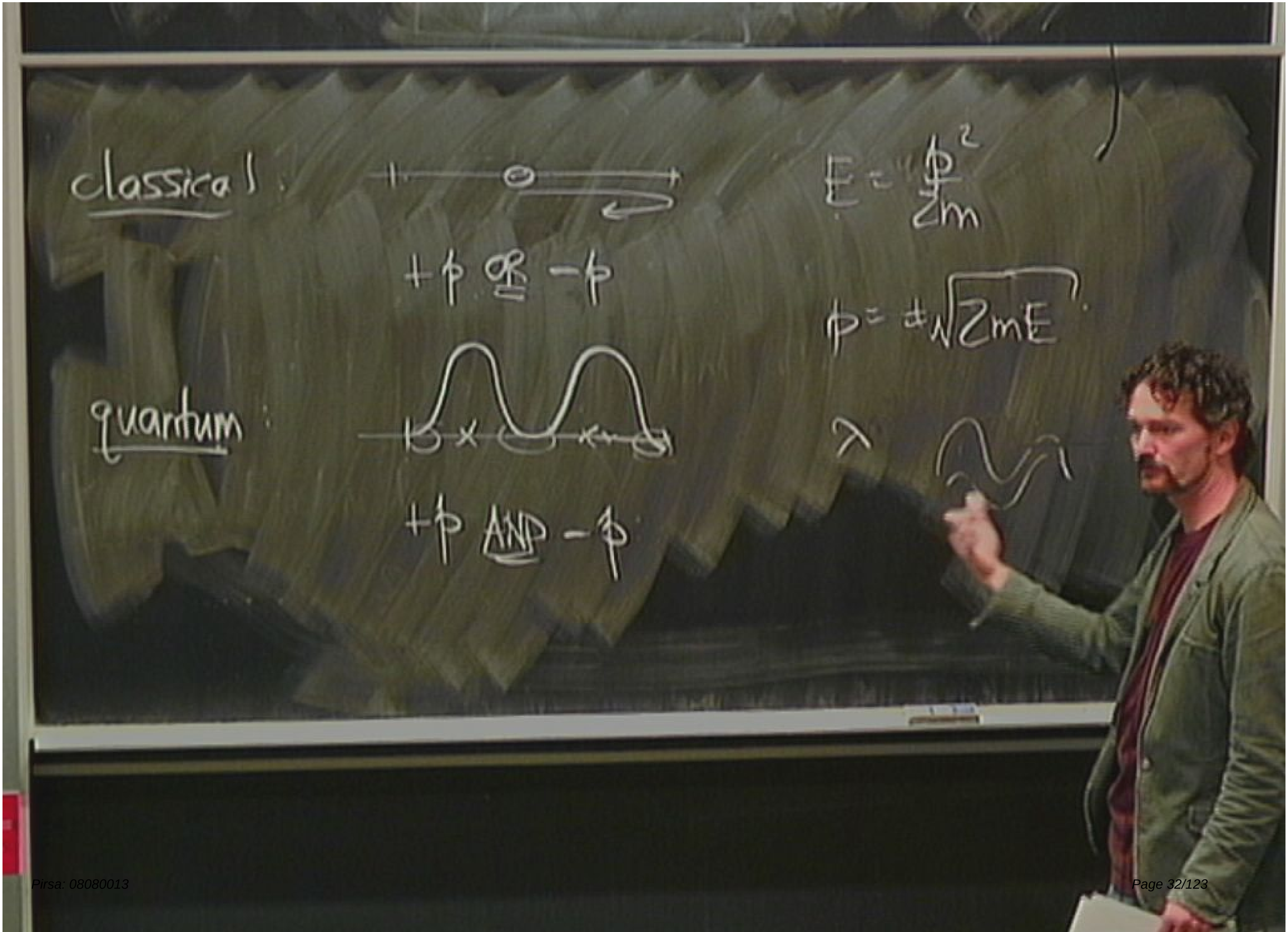

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2² =
E1 = 4 E0
ψ1 =
P1 = ψ1²
E0 (zero point)
ψ0 =
P0 = ψ0² =
0
h² / 8mL²
probability

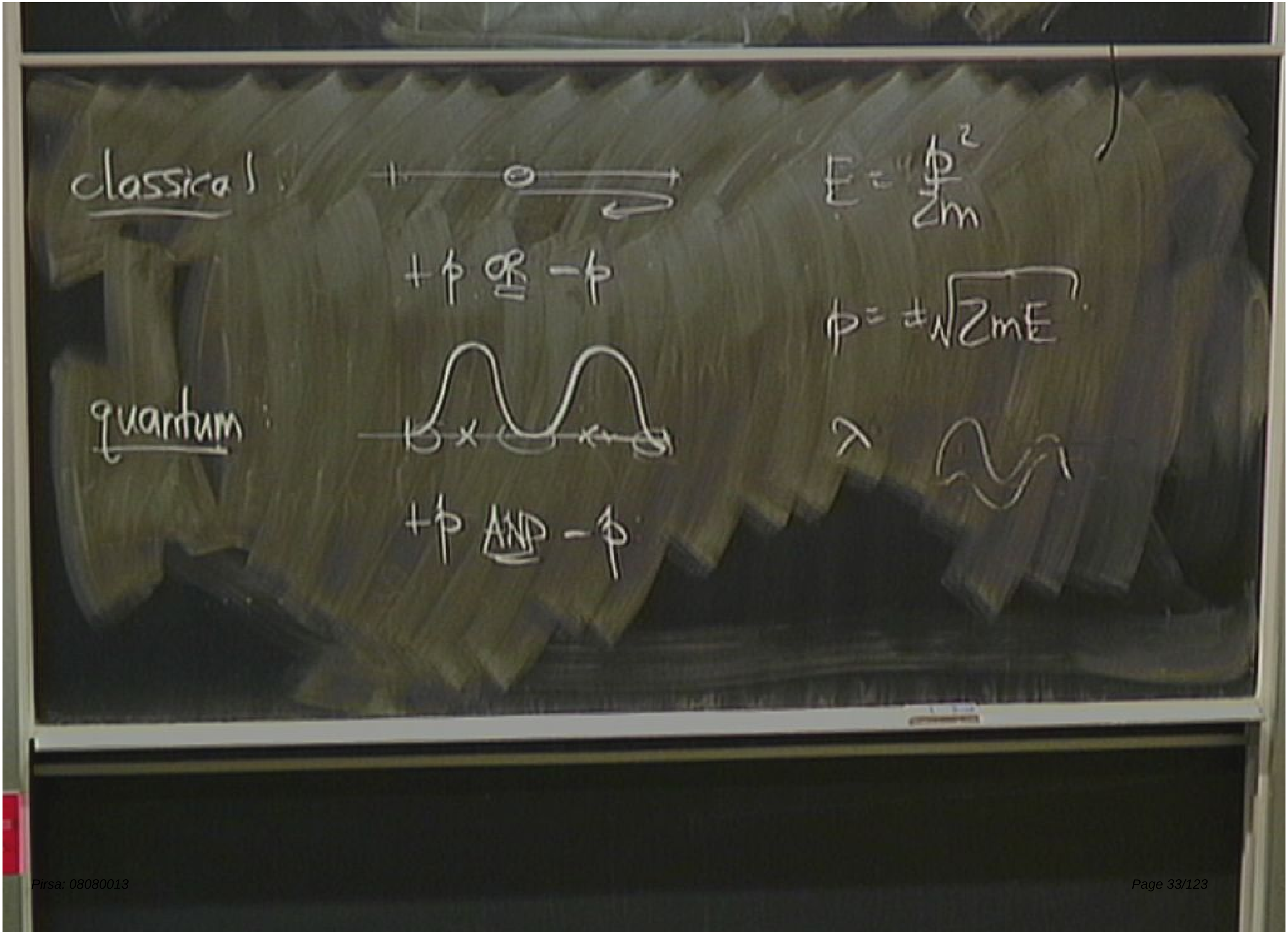


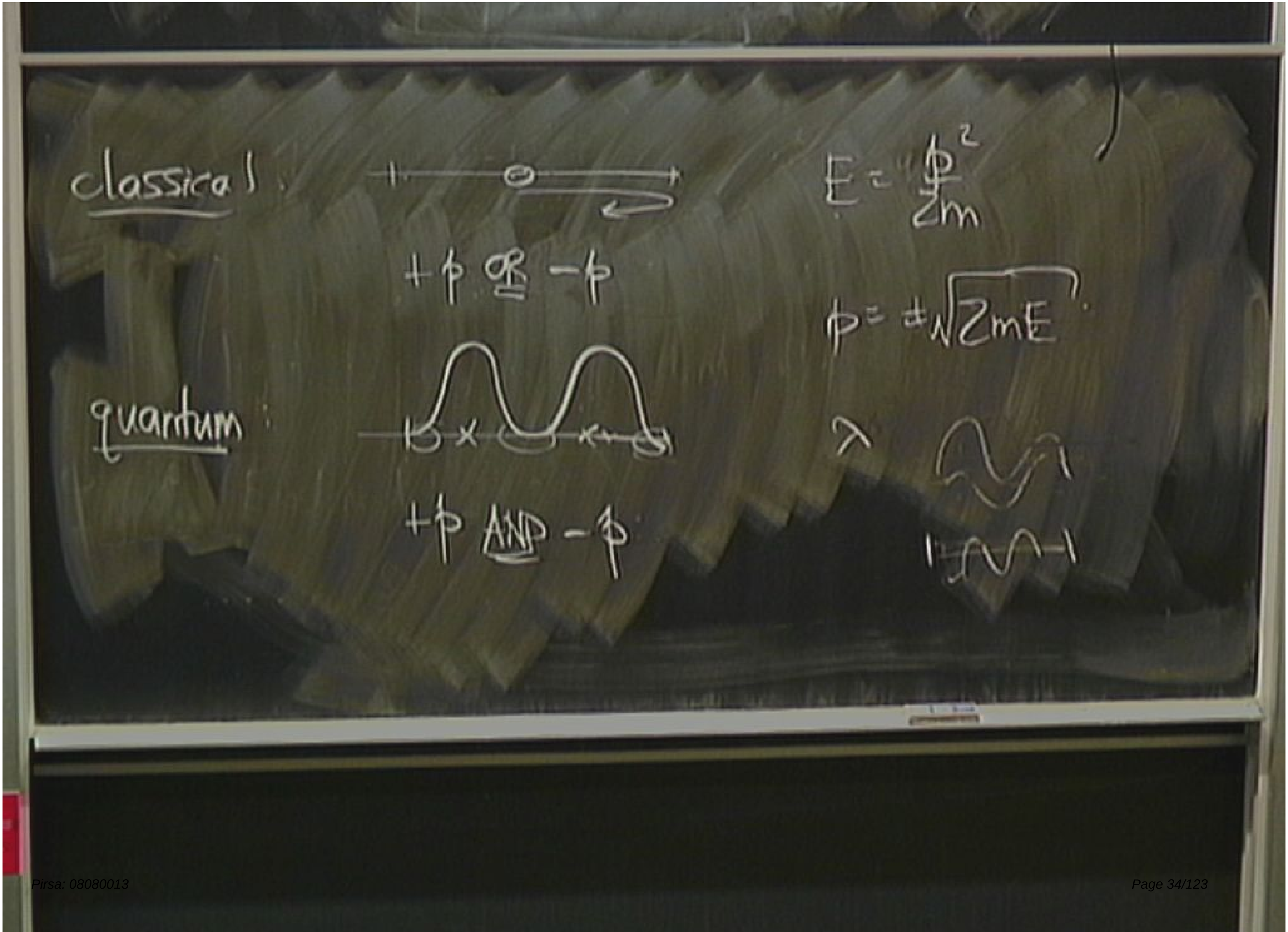
Energy
E2 = 9 E0
E1 = 4 E0
E0 (zero point)
0
ψ2 =
ψ1 =
ψ0 =
P2 = ψ2² =
P1 = ψ1²
P0 = ψ0² =
probability
class
quant

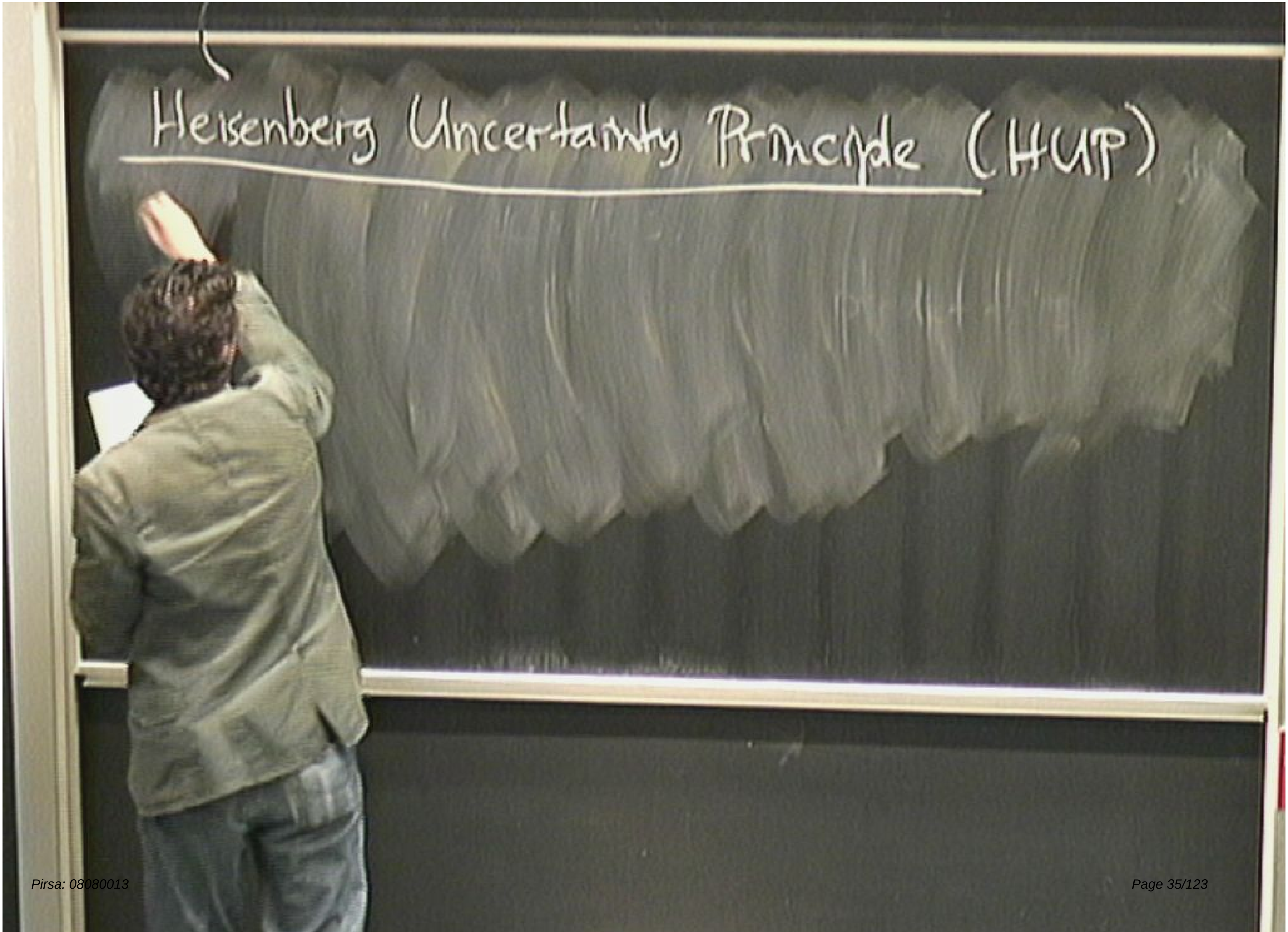

classical
E = p²/2m
+p OR −p
quantum
+p AND −p

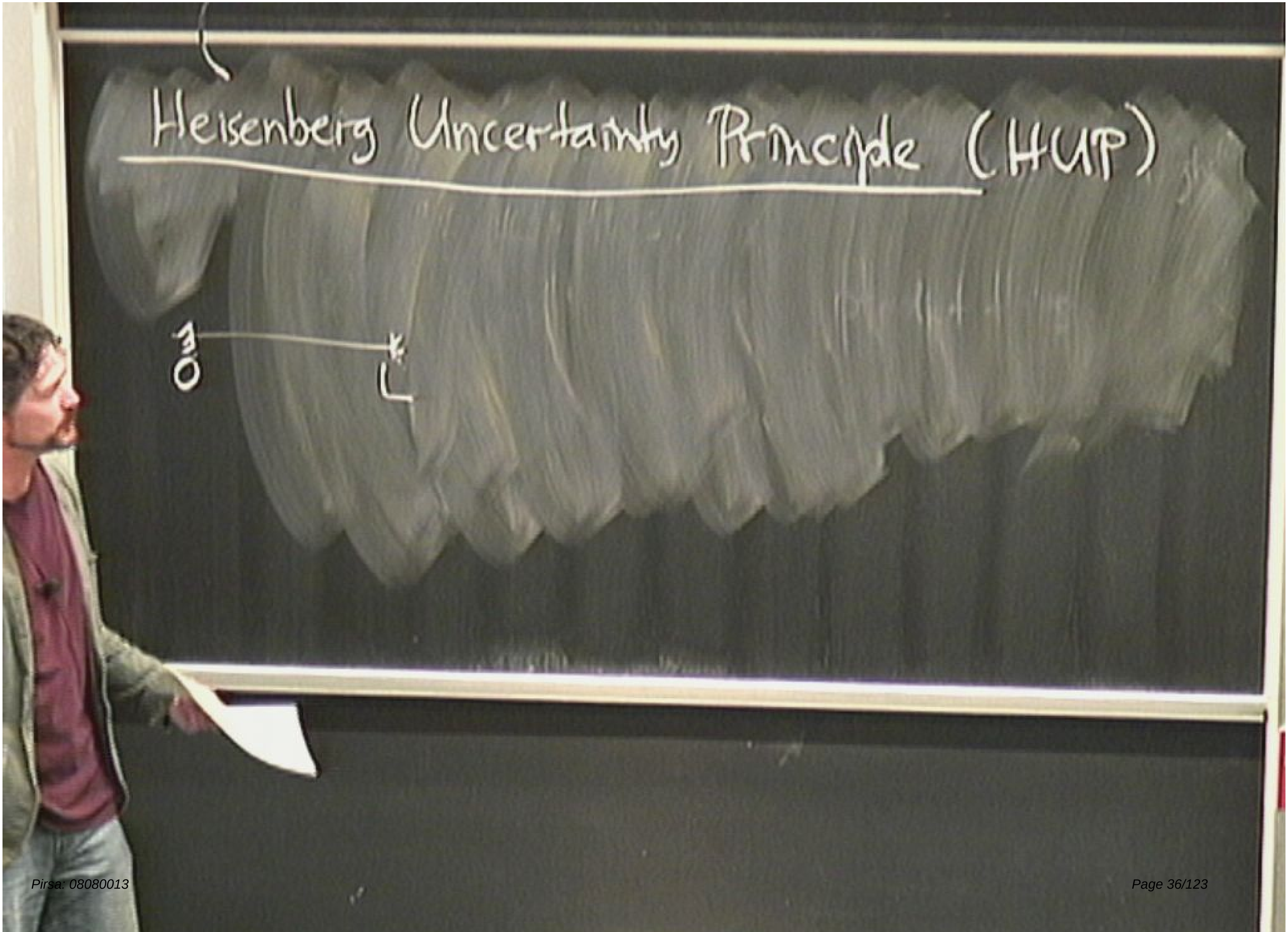

classical
+p OR -p
E = p²/2m
p = ±√2mE
quantum
+p AND -p

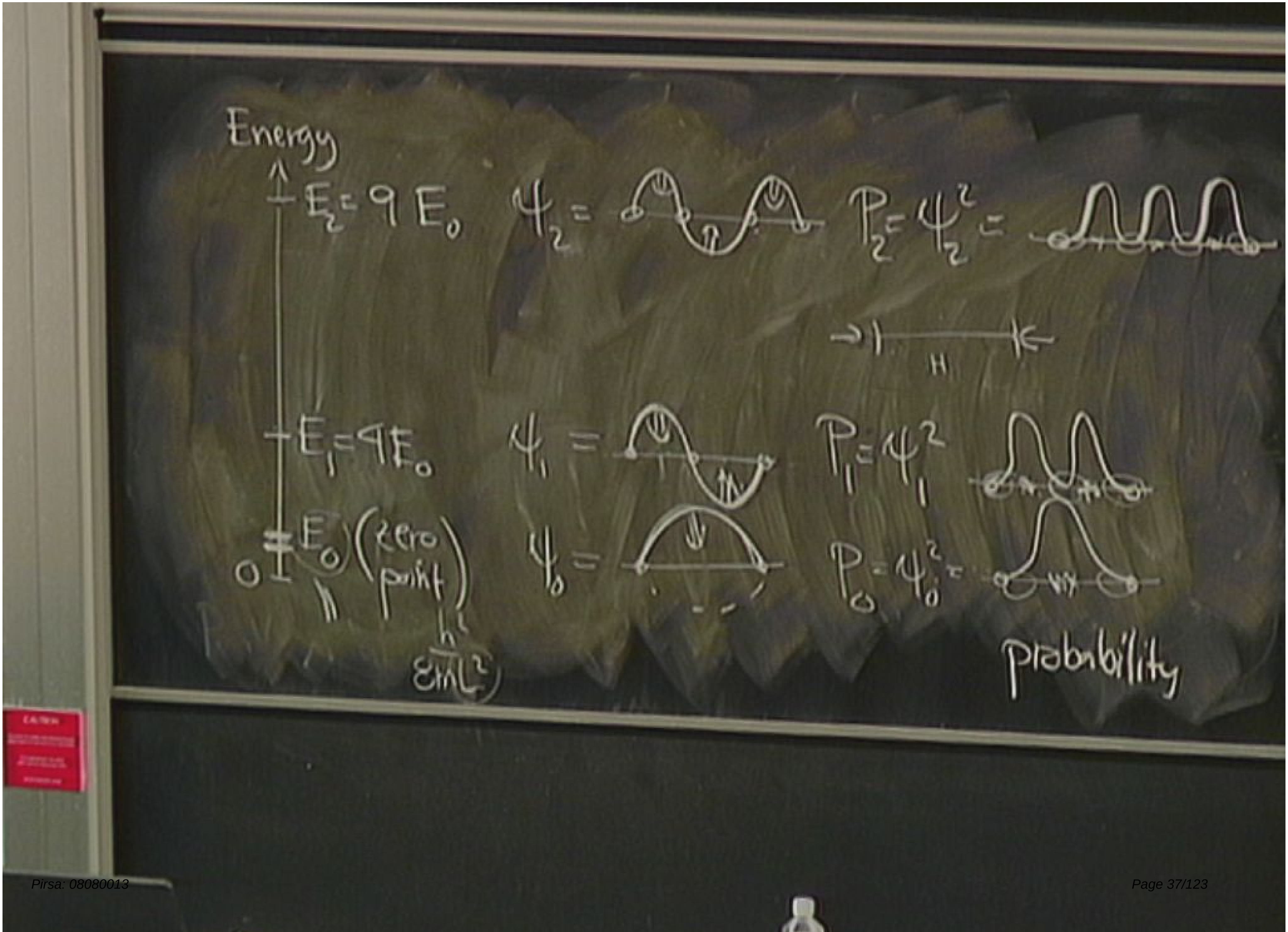

classical
+p OR −p
E = p²/2m
p = ±√2mE
quantum
+p AND −p
λ

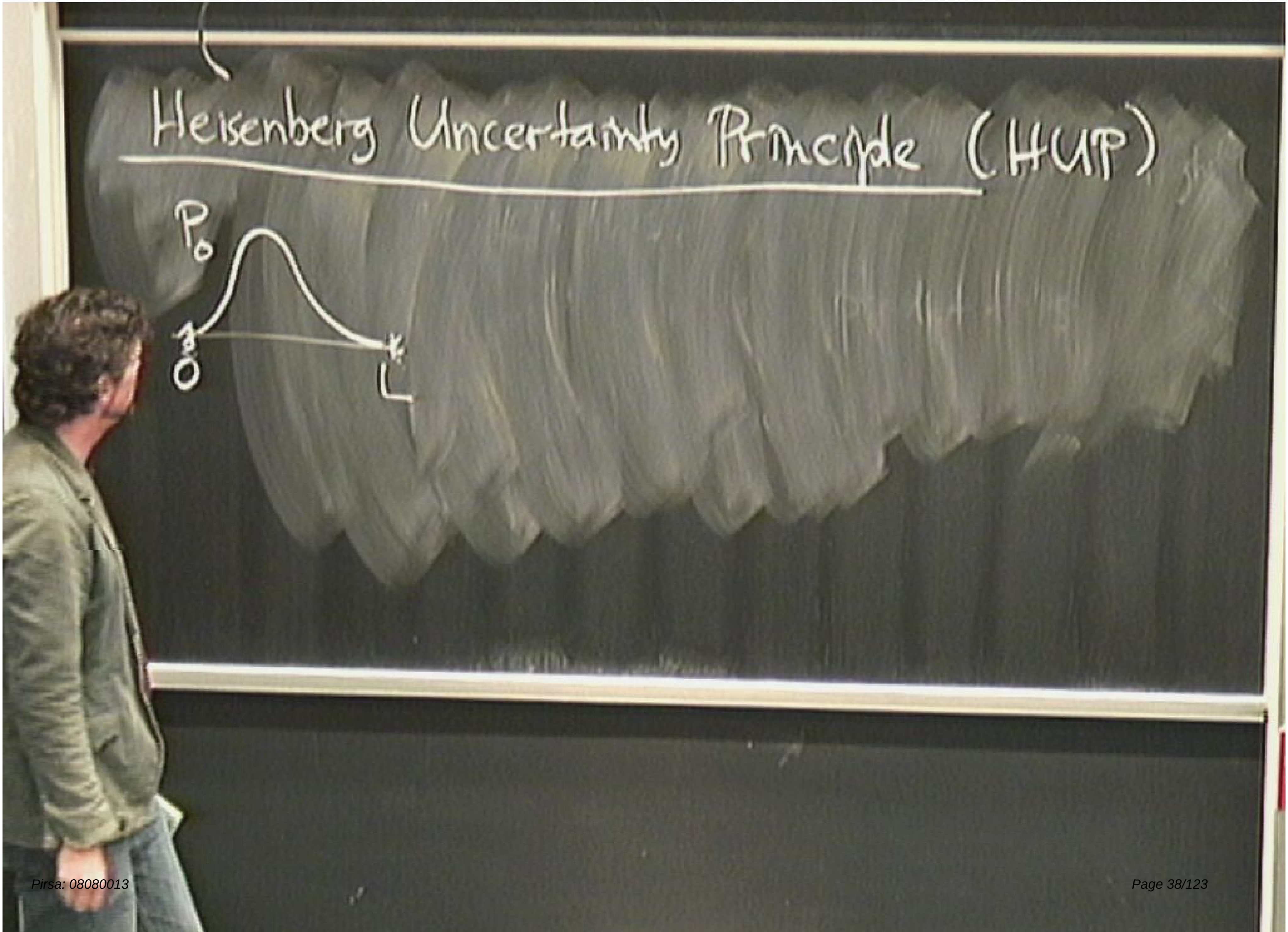

classical
+p OR -p
E = p²/2m
p = ±√2mE
quantum
+p AND -p
λ

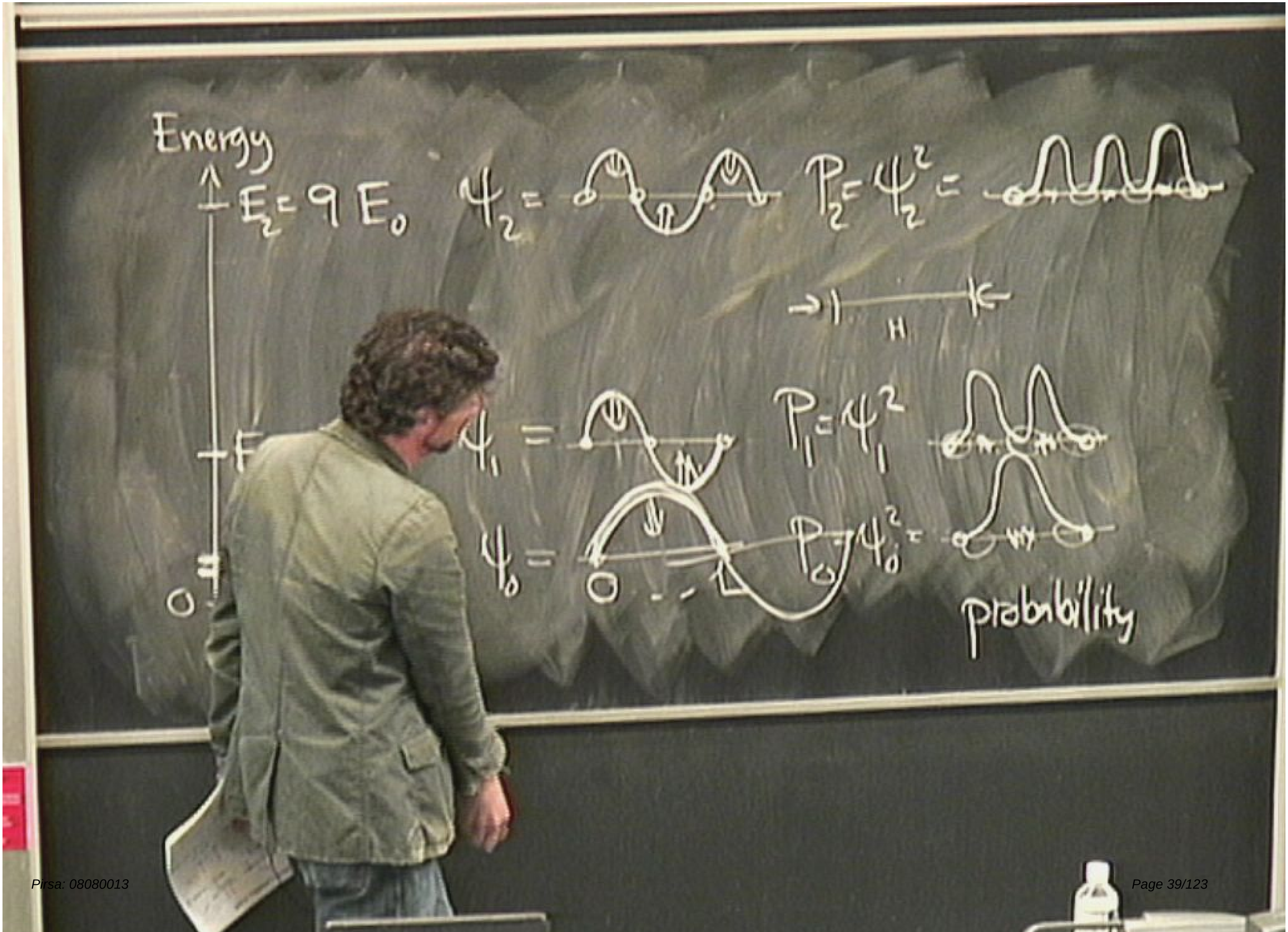

classical
E = p²/2m
+p OR −p
p = ±√2mE
quantum
+p AND −p


Heisenberg Uncertainty Principle (HUP)

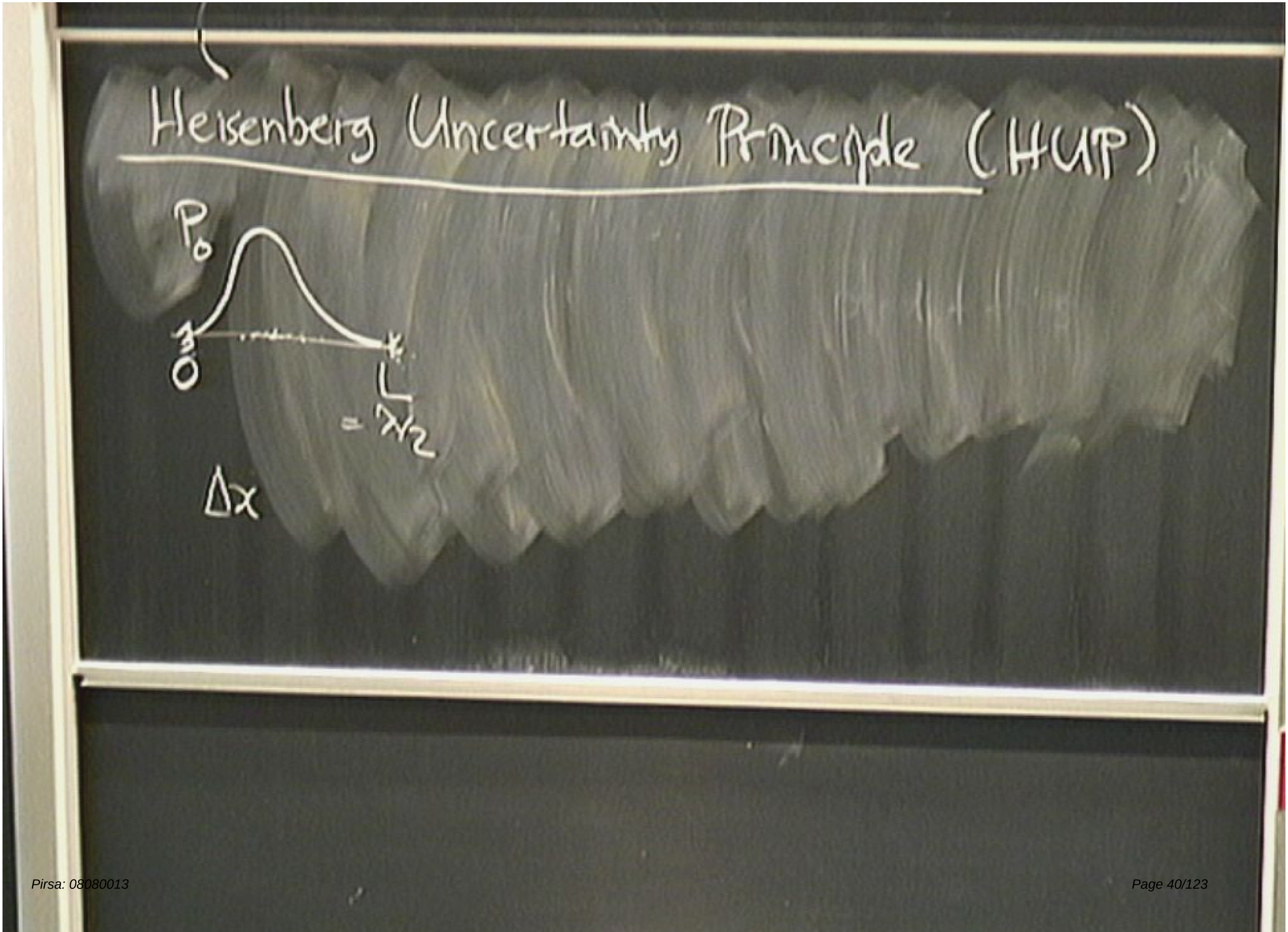

Heisenberg Uncertainty Principle (HUP)

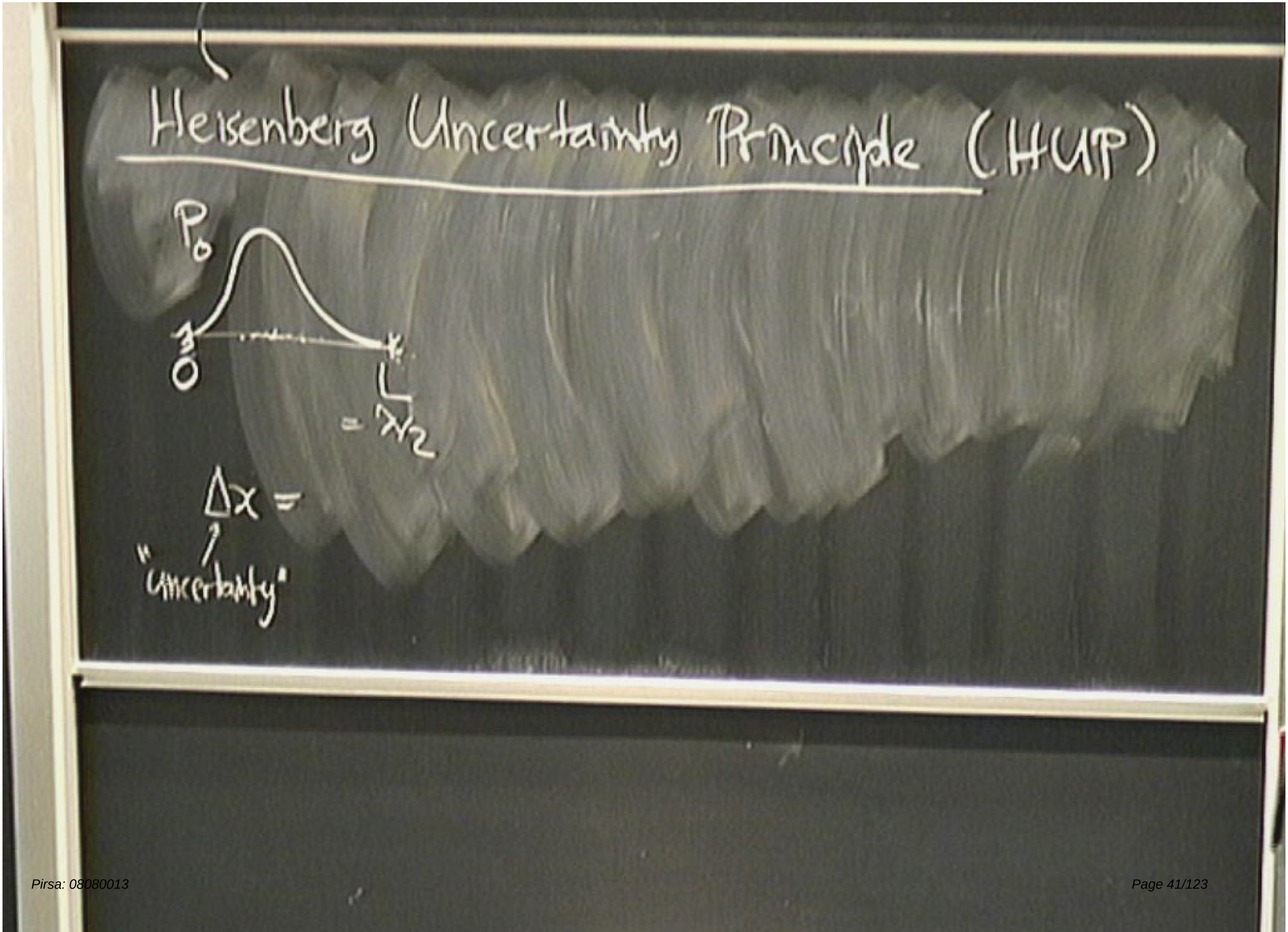

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2² =
H
E1 = 4E0
ψ1 =
P1 = ψ1²
E0 (zero point)
0
h²/8mL²
ψ0 =
P0 = ψ0² =
probability

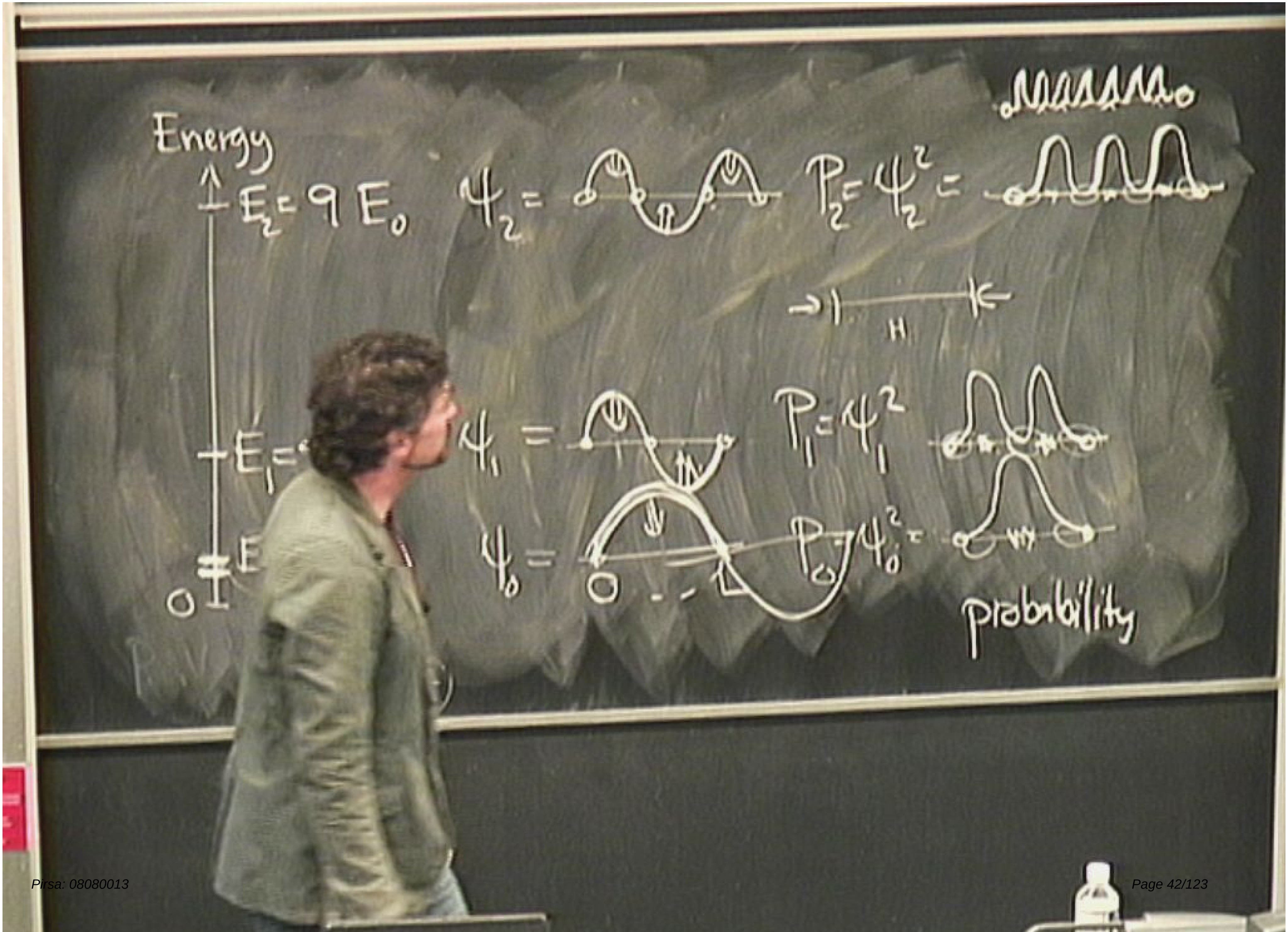

Heisenberg Uncertainty Principle (HUP)
P0
0
L

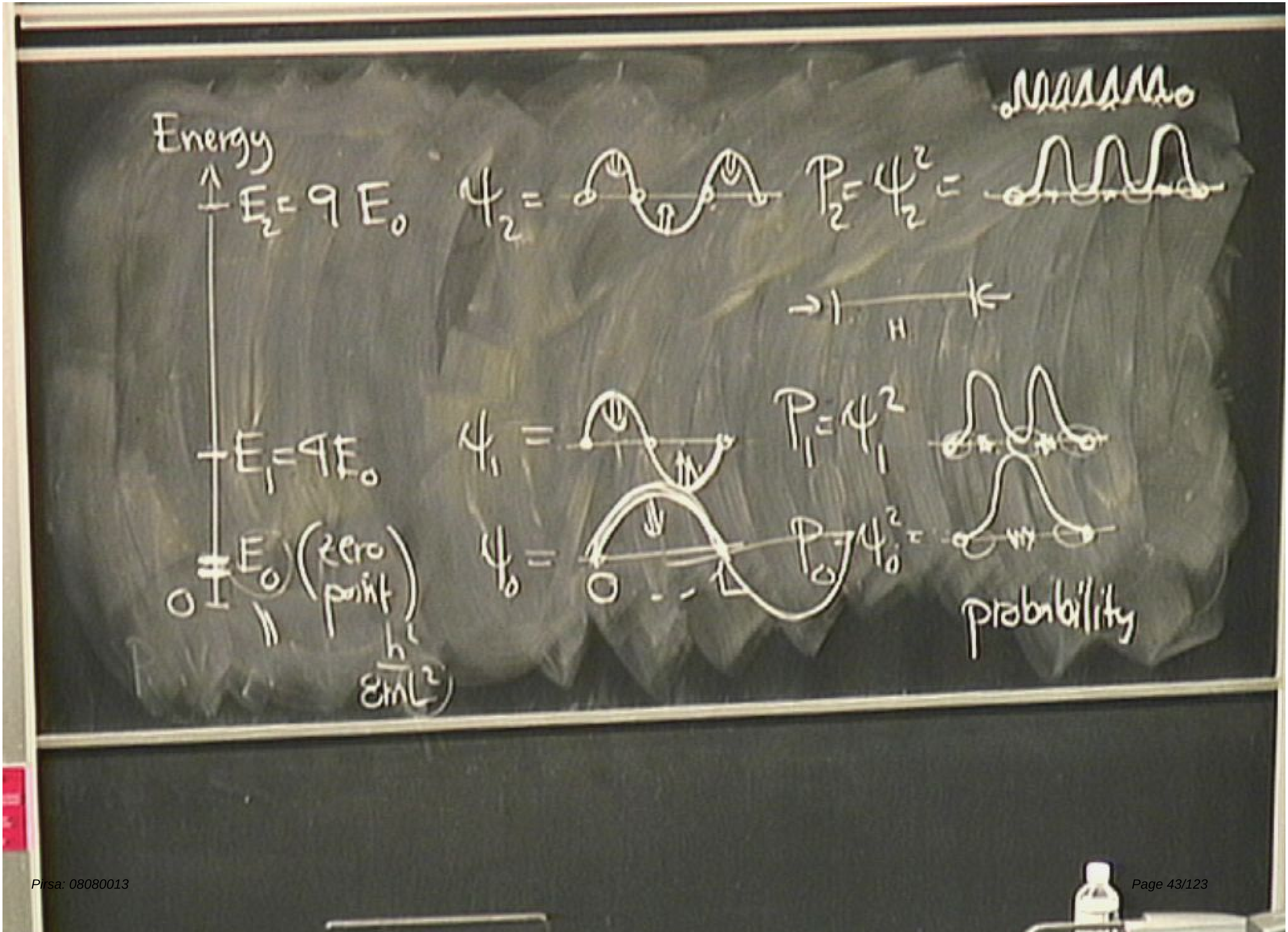


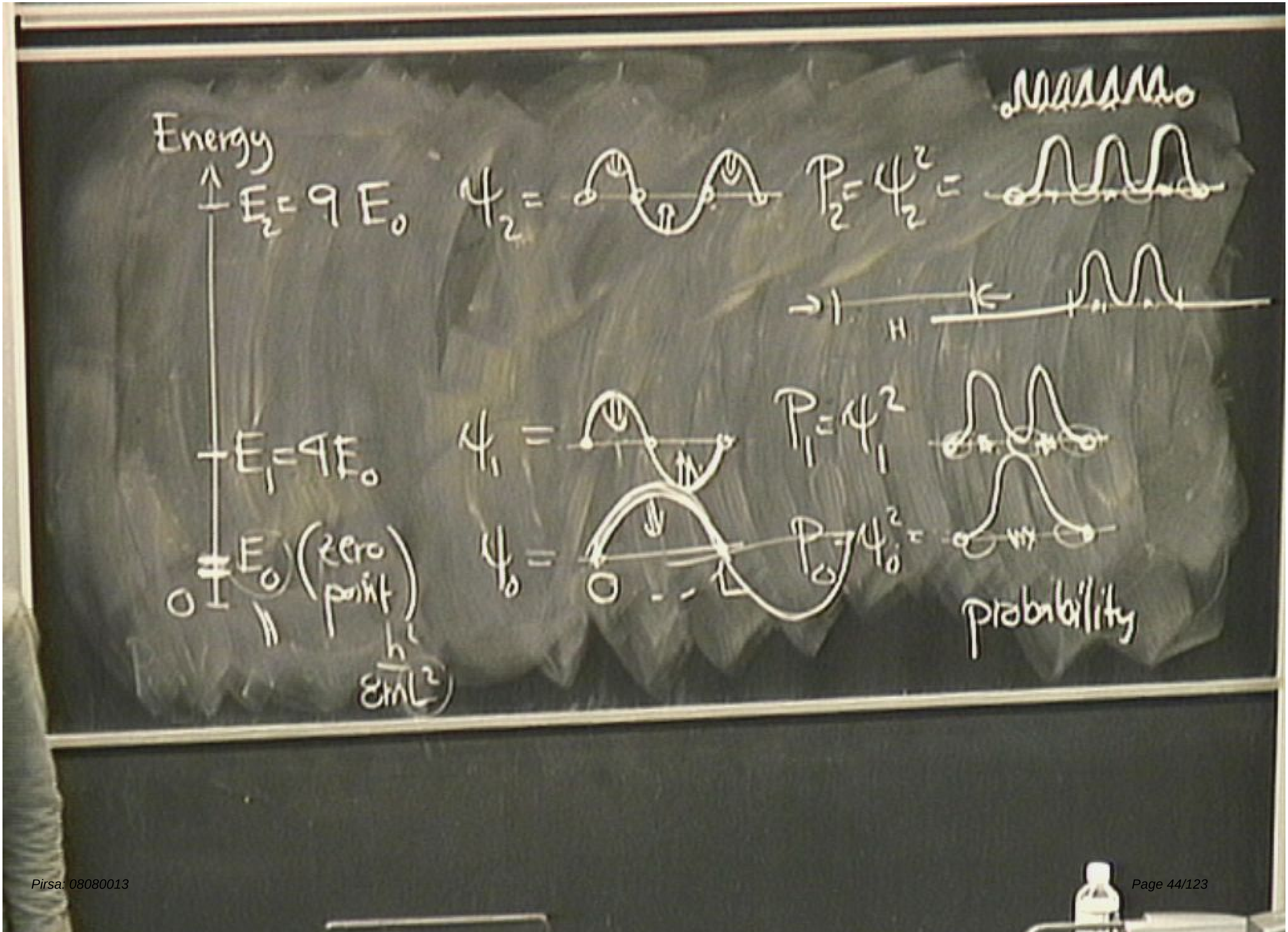
Energy
$E_2 = 9 E_0$
$\psi_2 =$
$P_2 = \psi_2^2 =$
H
$\psi_1 =$
$P_1 = \psi_1^2$
$\psi_0 =$
$P_0 = \psi_0^2 =$
0
probability

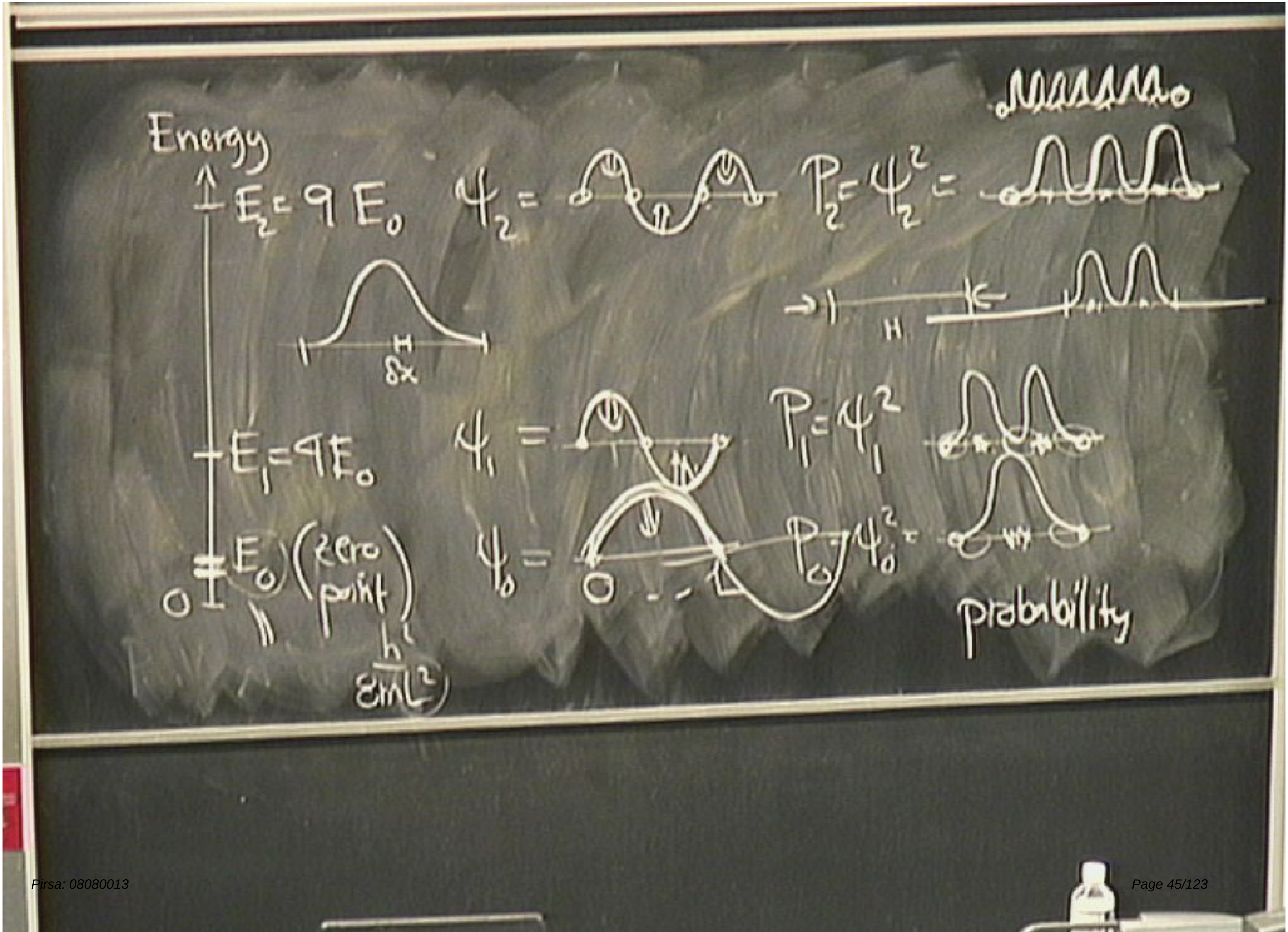

Heisenberg Uncertainty Principle (HUP)
P_0
0
L
$= \lambda/2$
Δx

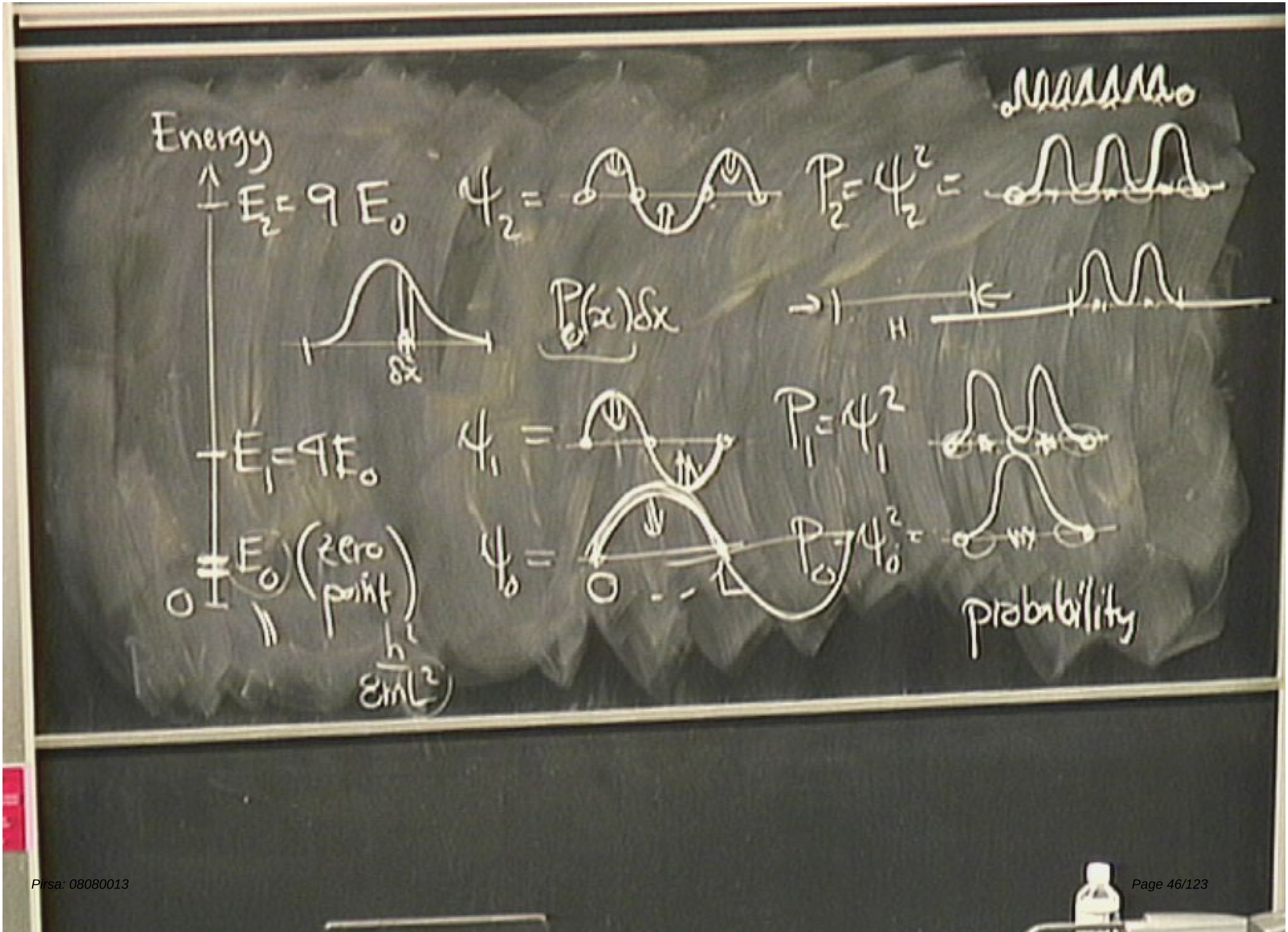

Heisenberg Uncertainty Principle (HUP)
P0
0
L
= λ/2
Δx =
"uncertainty"

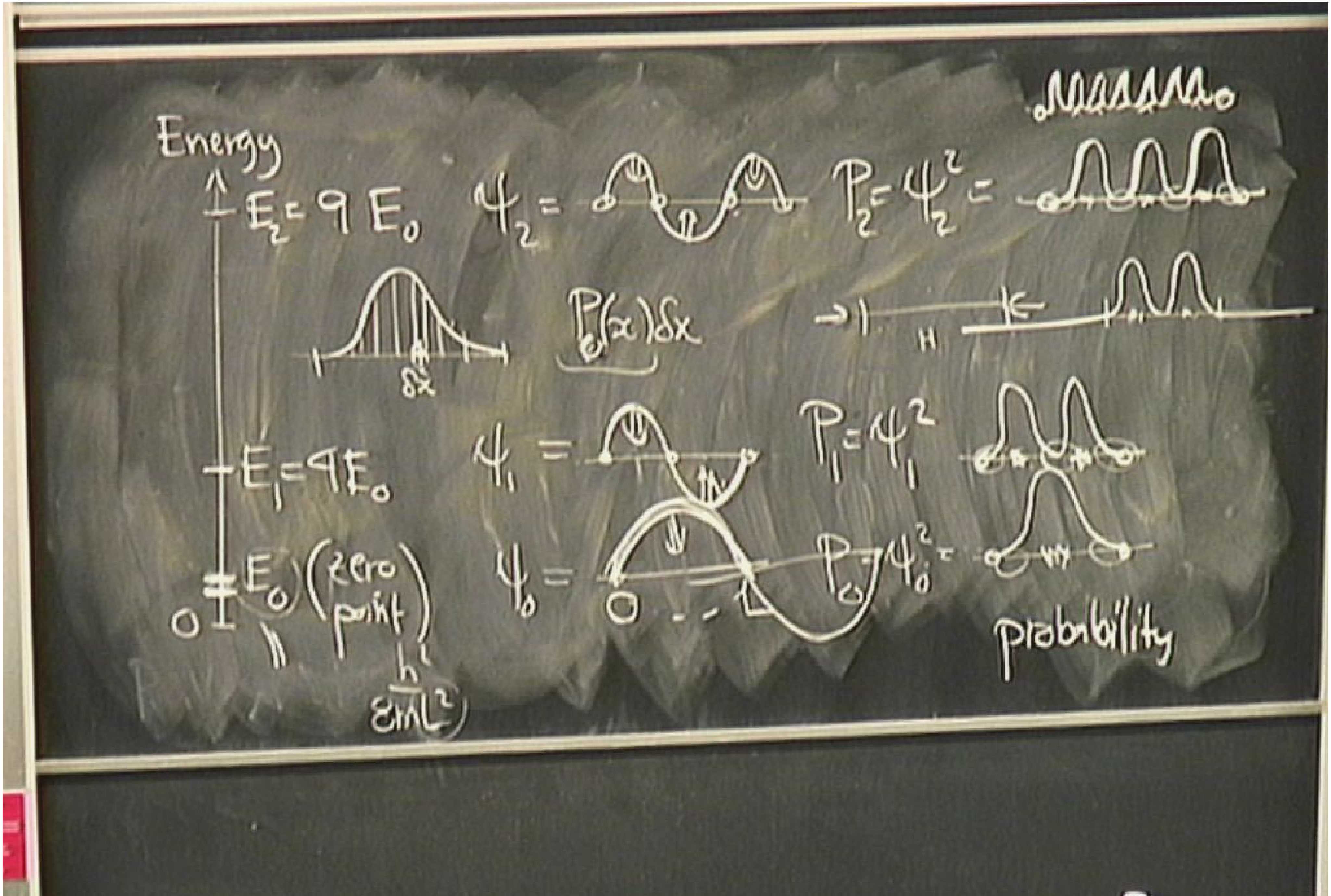

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2² =
H
ψ1 =
P1 = ψ1²
E1 =
ψ0 =
P0 = ψ0² =
0
0
L
probability


Energy
E_2 = 9 E_0
E_1 = 4 E_0
E_0 (zero point)
0
h^2 / 8mL^2
ψ_2 =
ψ_1 =
ψ_0 =
P_2 = ψ_2^2 =
P_1 = ψ_1^2
P_0 = ψ_0^2 =
H
probability

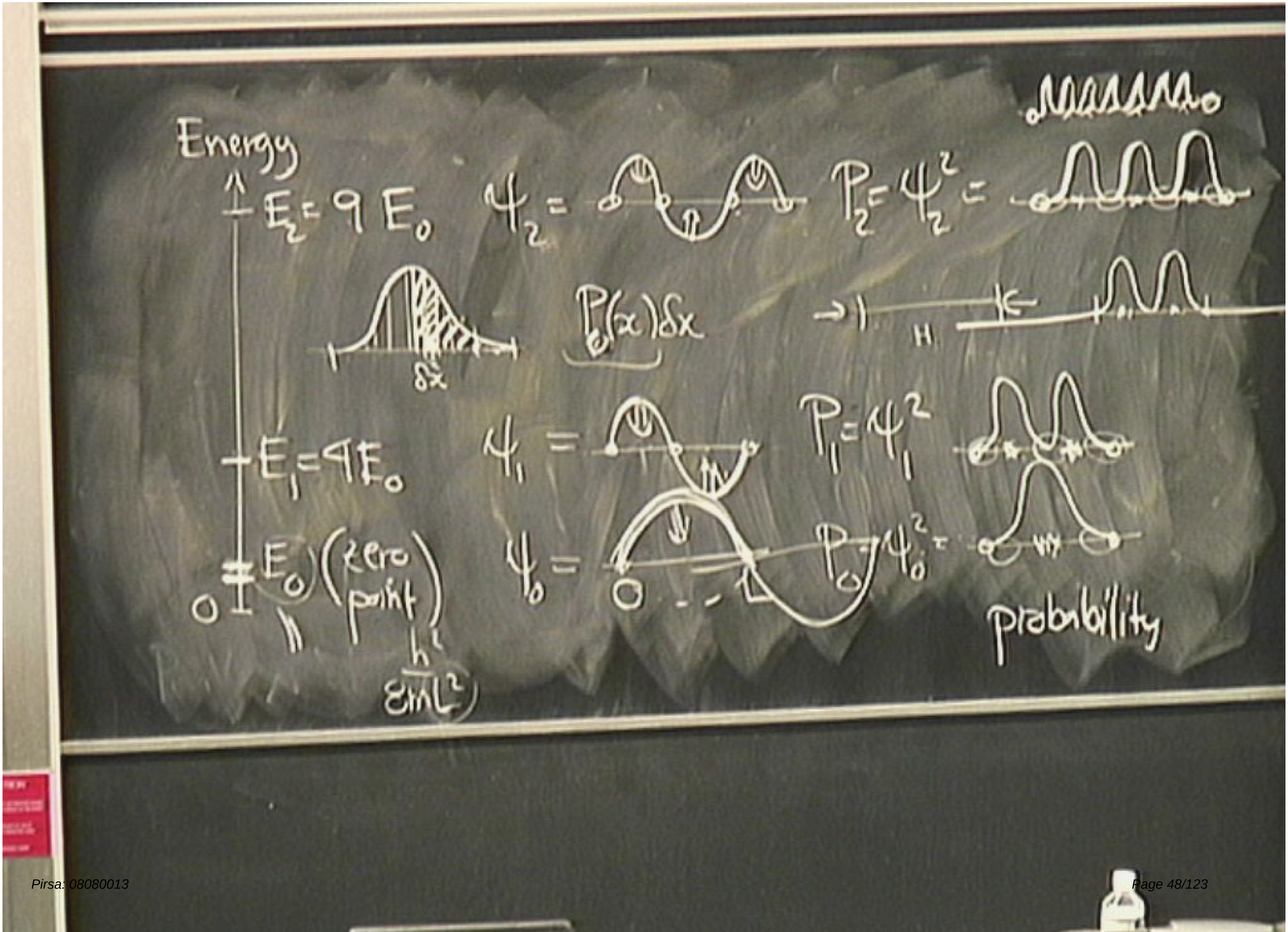

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2² =
E1 = 4 E0
ψ1 =
P1 = ψ1²
E0 (zero point)
0
h²/8mL²
ψ0 =
P0 = ψ0² =
probability

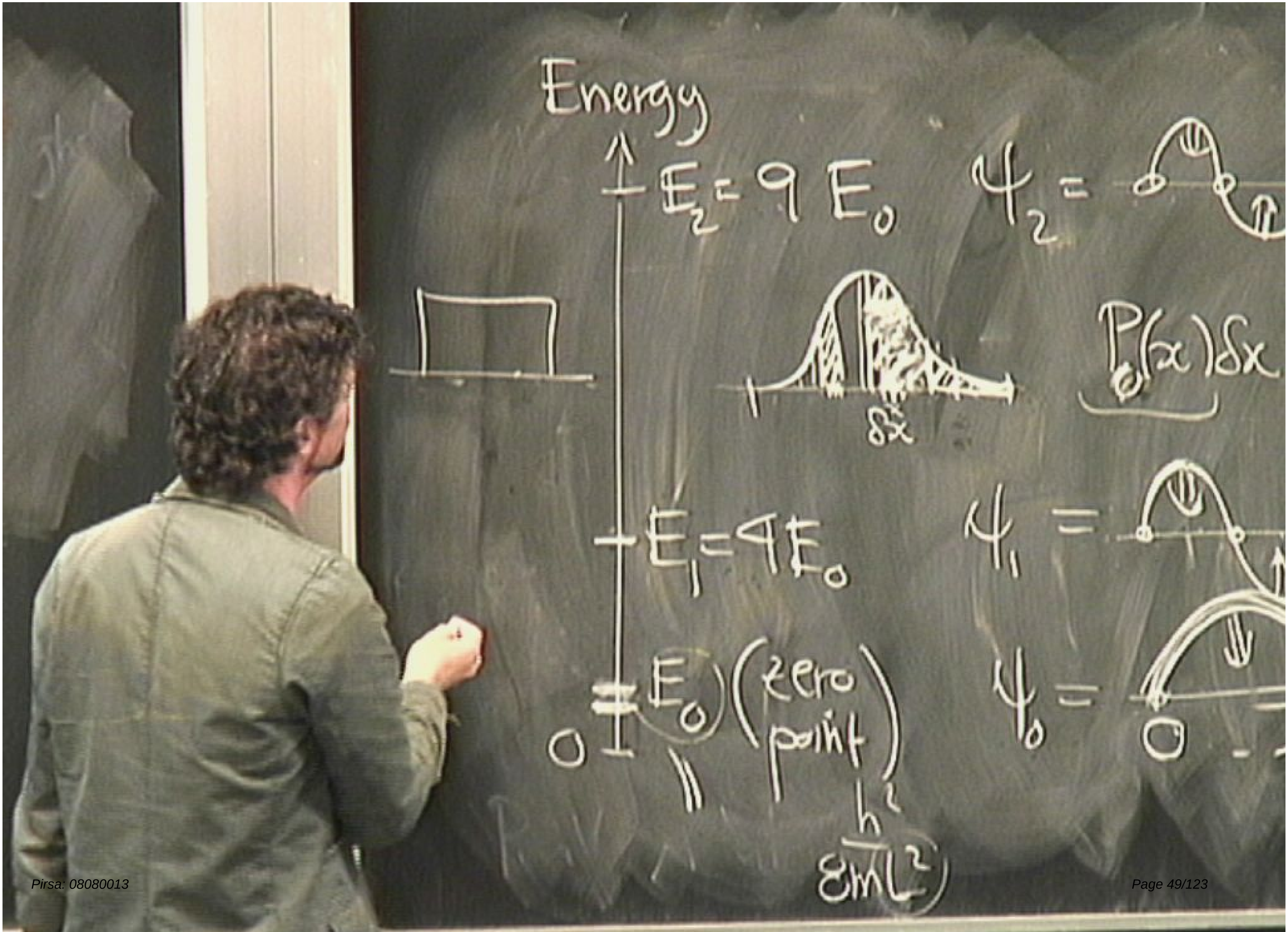

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2^2 =
δx
E1 = 4E0
ψ1 =
P1 = ψ1^2
E0 (zero point)
0
h^2 / 8mL^2
ψ0 =
P0 = ψ0^2 =
probability

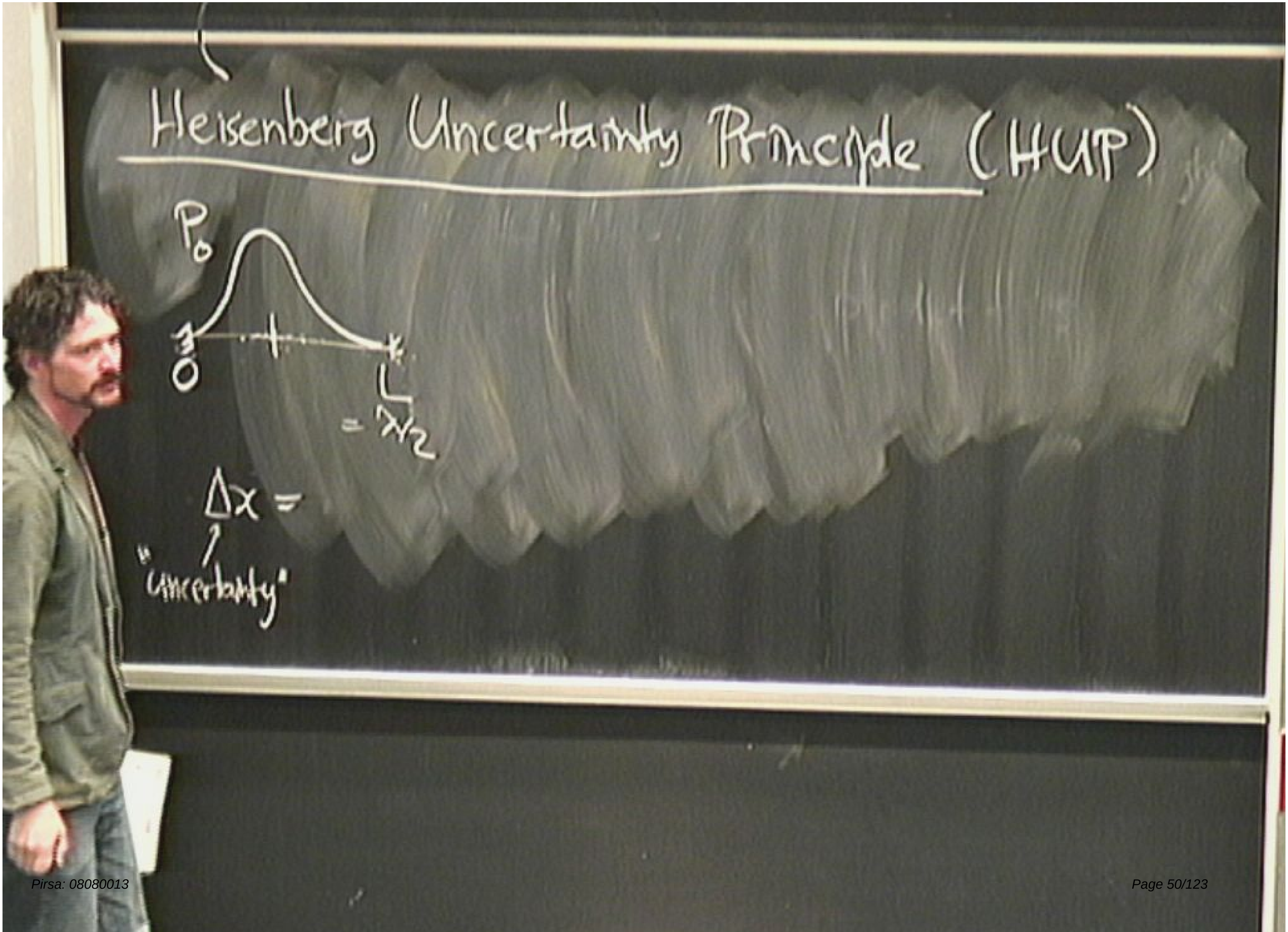

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2^2 =
P(x)δx
δx
E1 = 4E0
ψ1 =
P1 = ψ1^2
E0 (zero point)
ψ0 =
P0 = ψ0^2 =
0
h^2 / 8mL^2
probability

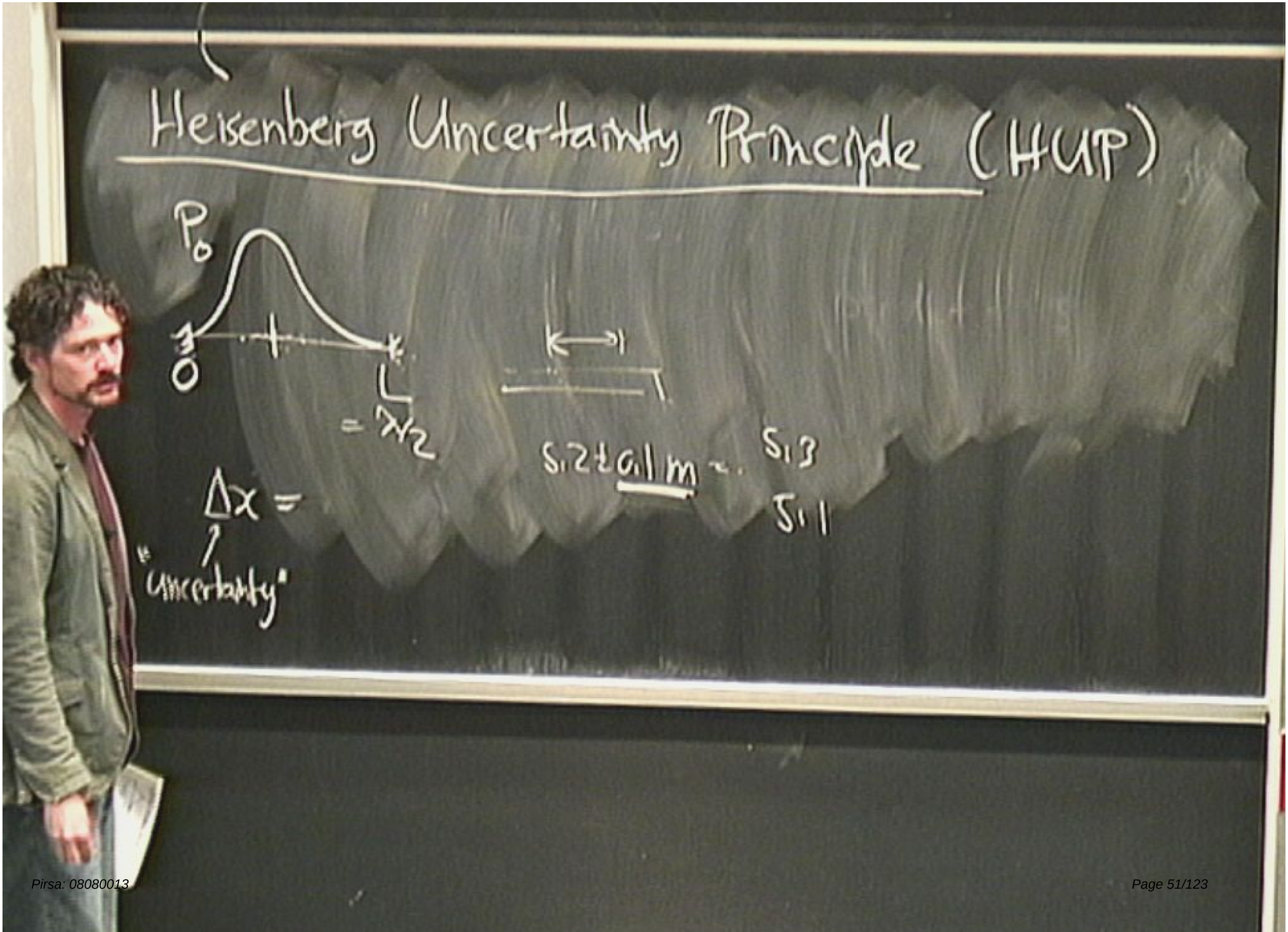


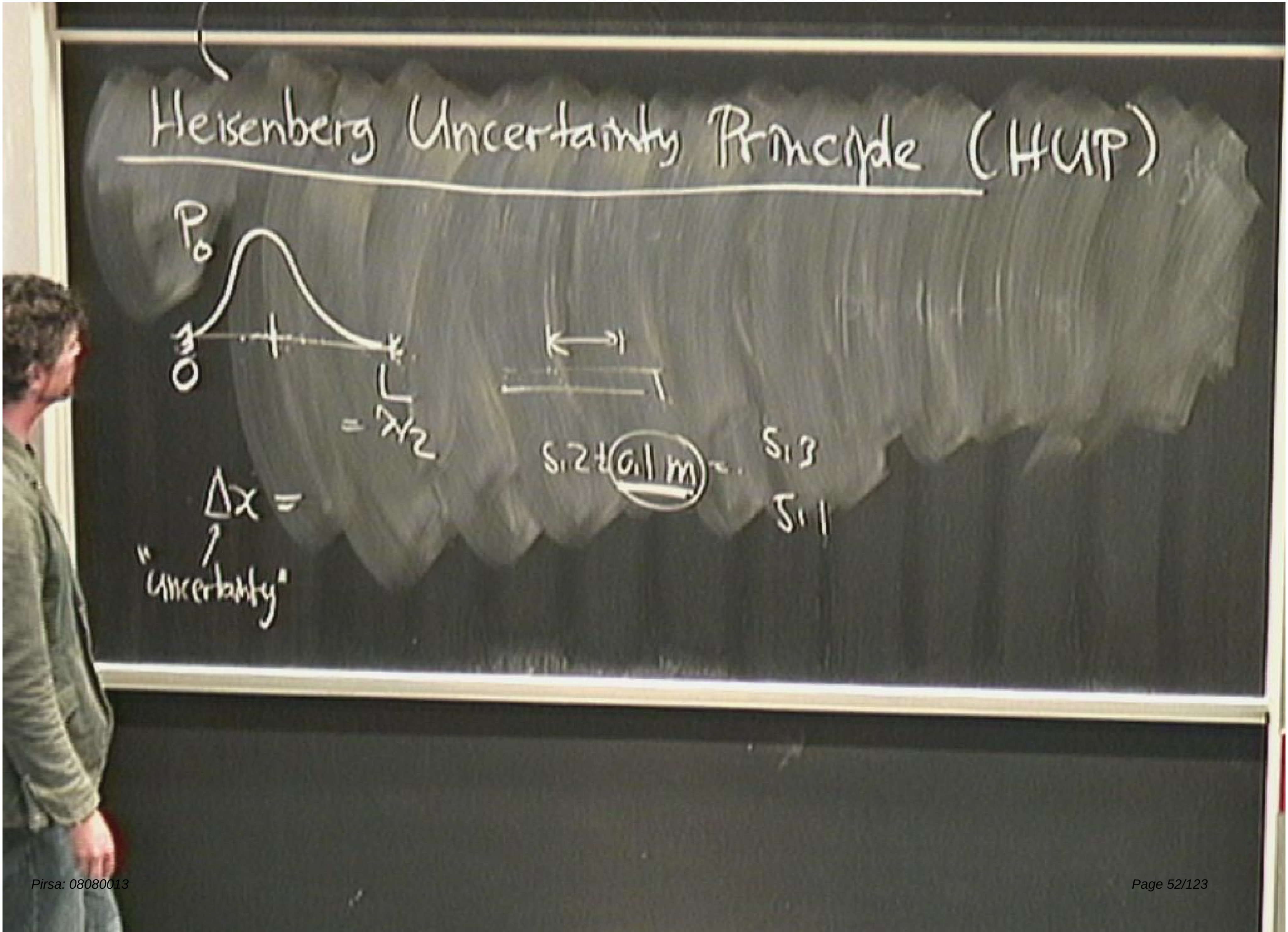
Energy
E2 = 9 E0
ψ2 =
P2 = ψ2² =
P(x)δx
δx
E1 = 4E0
ψ1 =
P1 = ψ1²
E0 (zero point)
ψ0 =
P0 = ψ0² =
0
h²/8mL²
probability

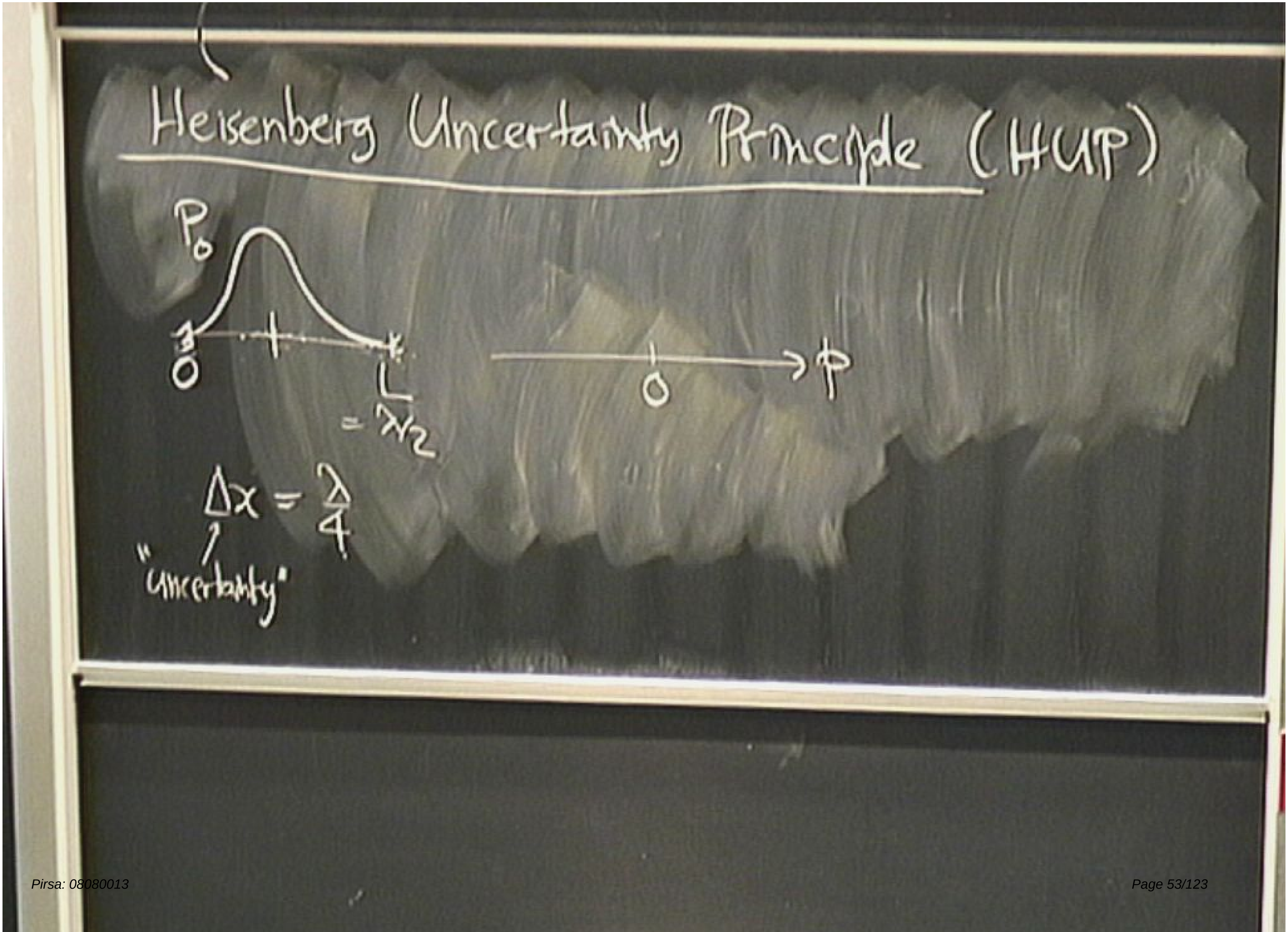

Energy
E2 = 9 E0
ψ2 =
P2 = ψ2^2 =
P0(x)δx
δx
H
E1 = 4E0
ψ1 =
P1 = ψ1^2
E0 (zero point)
h^2 / 8mL^2
0
ψ0 =
0 - - L
P0 = ψ0^2 =
probability

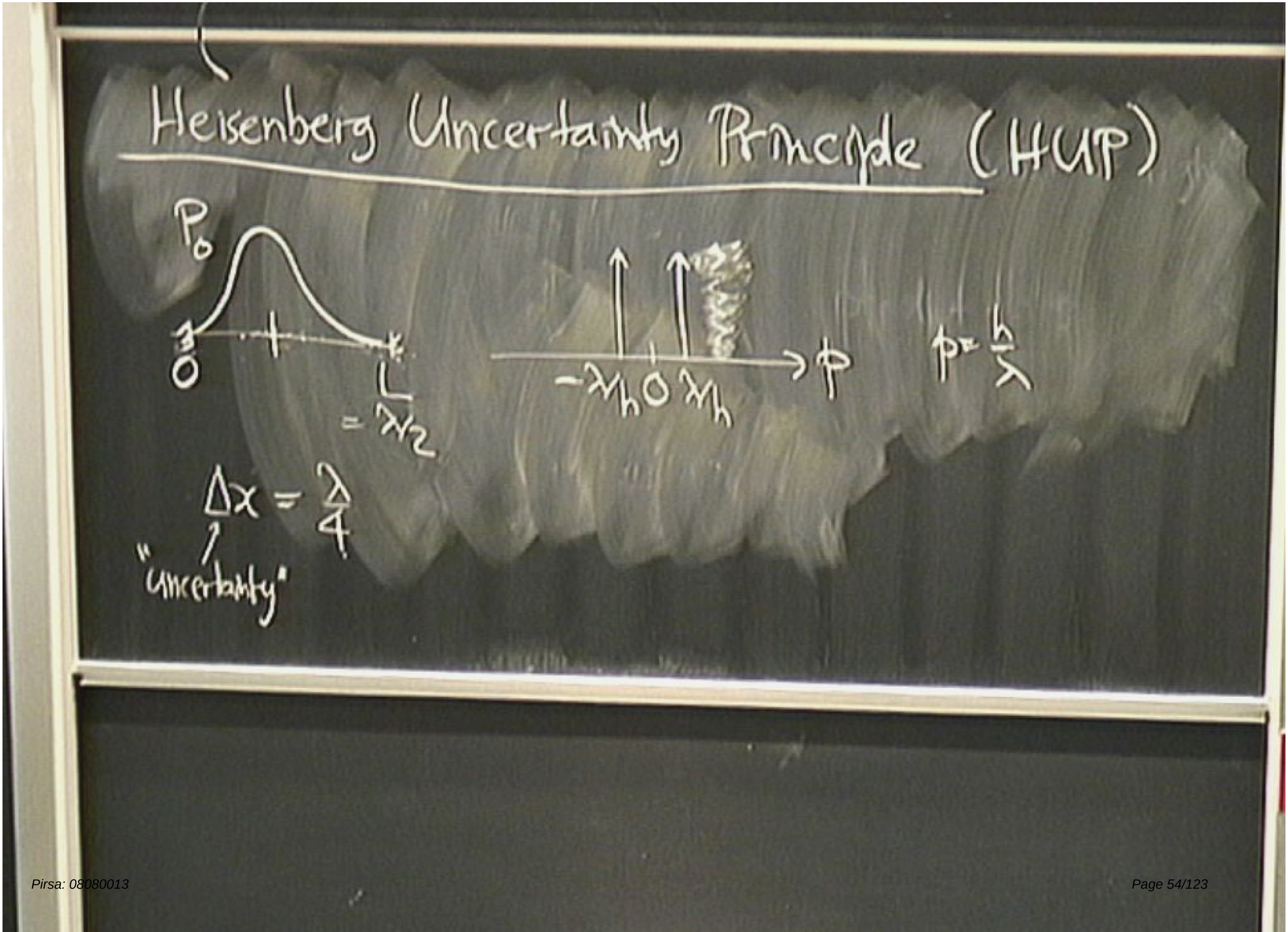

Energy
E2 = 9 E0
ψ2 =
δx
P0(x)δx
E1 = 4 E0
ψ1 =
E0 (zero point)
ψ0 =
0
h²
8mL²

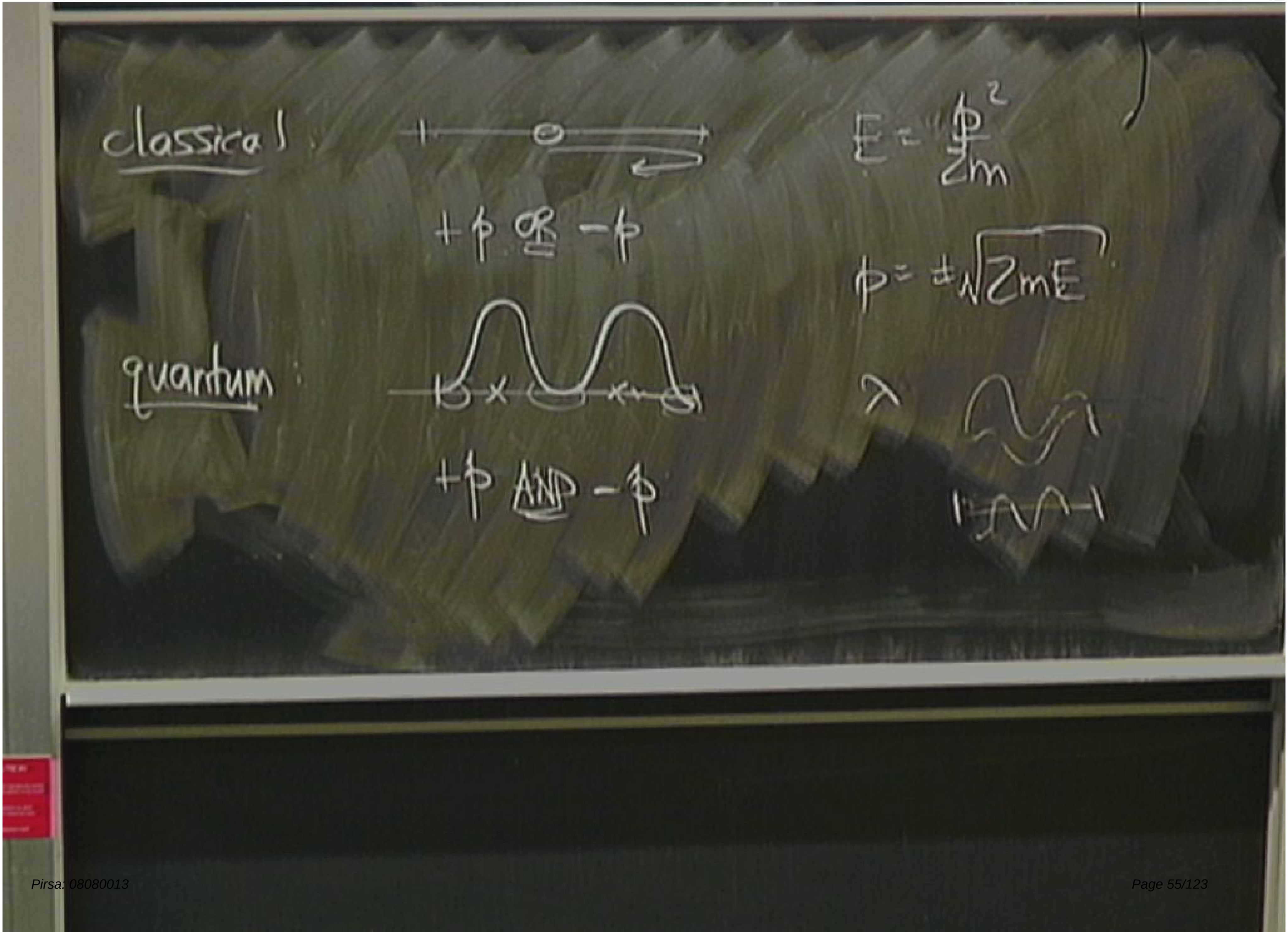

Heisenberg Uncertainty Principle (HUP)
P0
0
L
= λ/2
Δx =
"uncertainty"

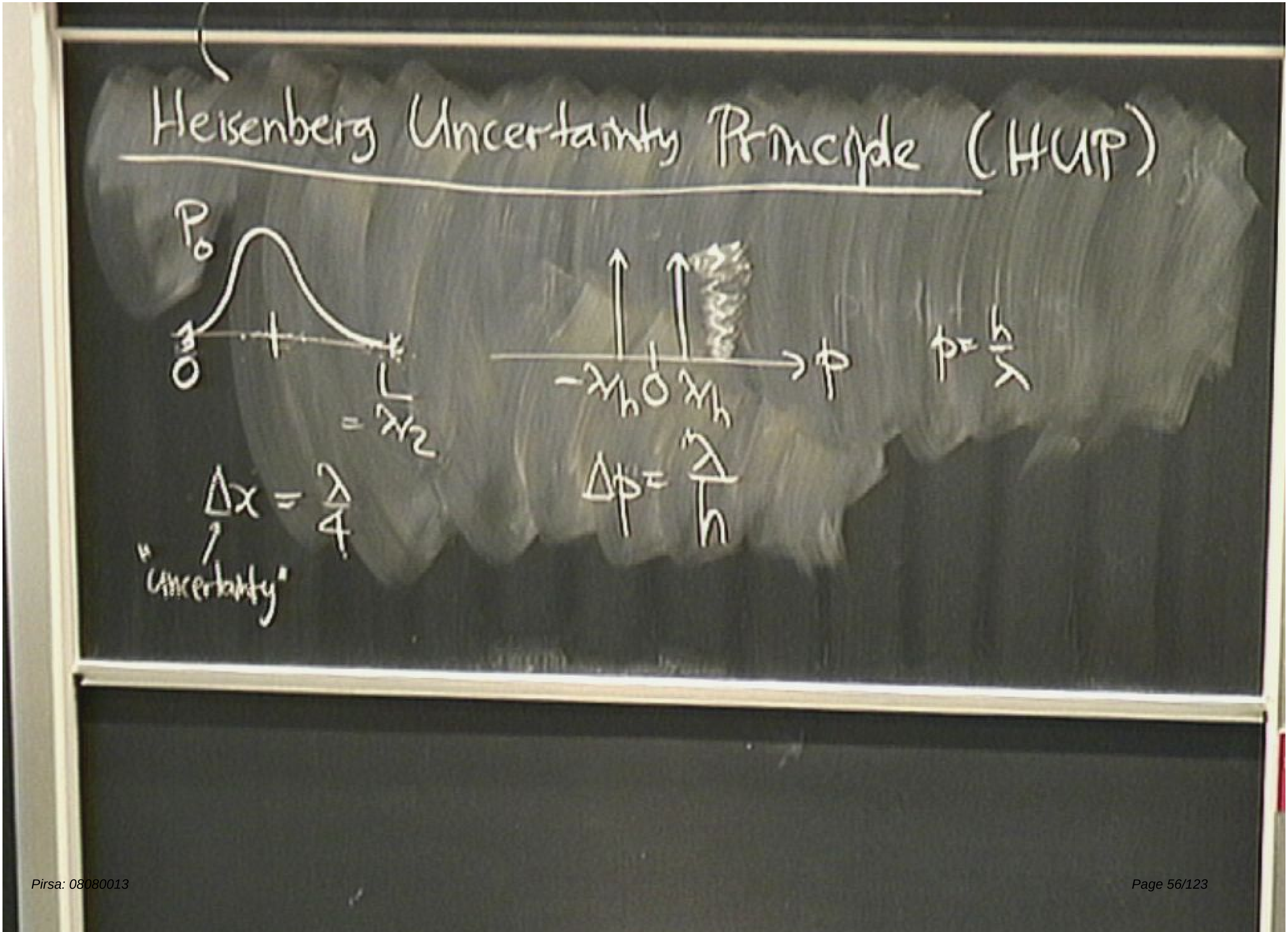

Heisenberg Uncertainty Principle (HUP)
P0
0
L
= λ/2
Δx =
"uncertainty"
5.2 ± 0.1 m
5.3
5.1

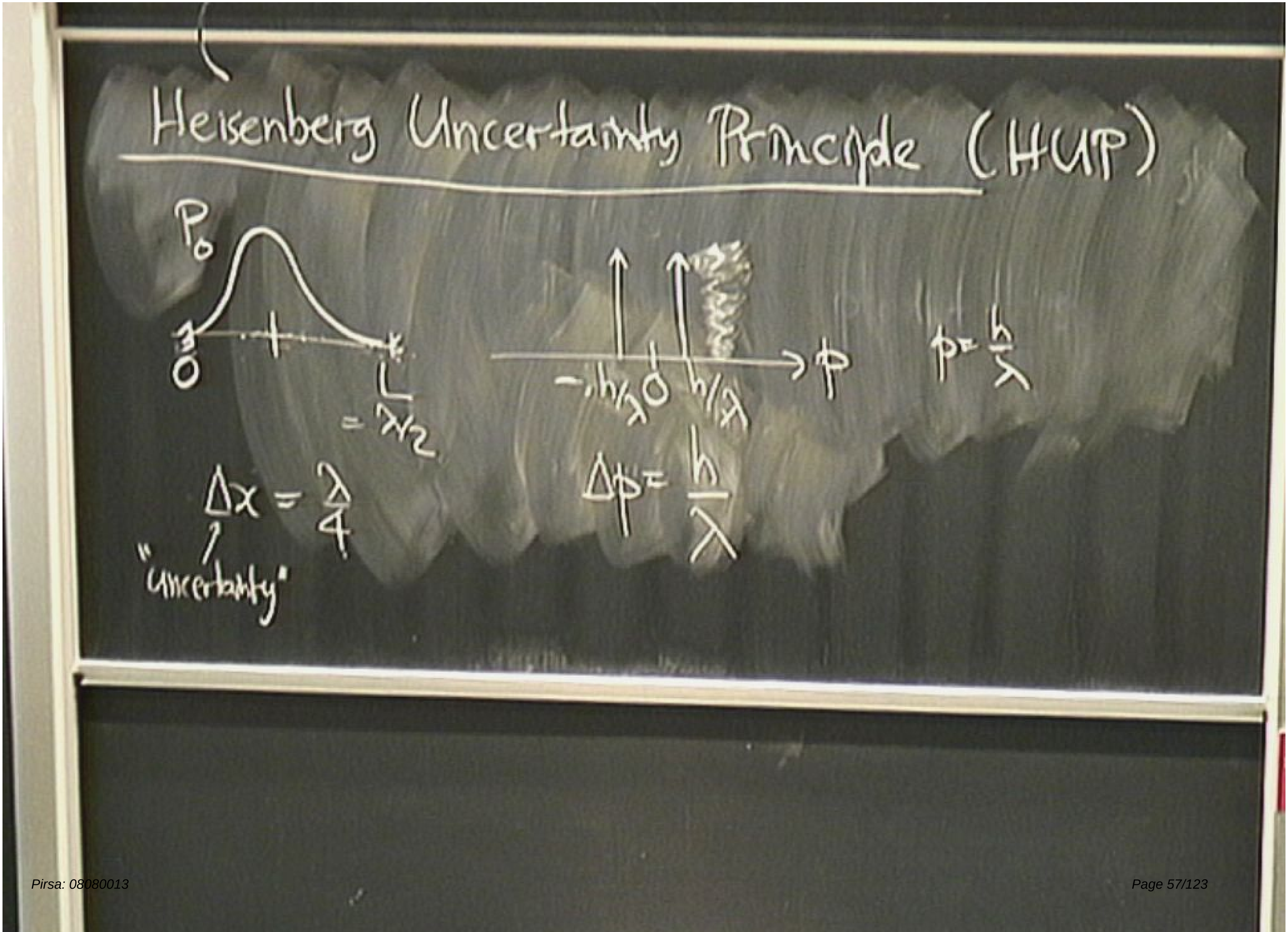

Heisenberg Uncertainty Principle (HUP)
P0
0
L
Δx =
"uncertainty"
5.2 ± 0.1 m
5.3
5.1

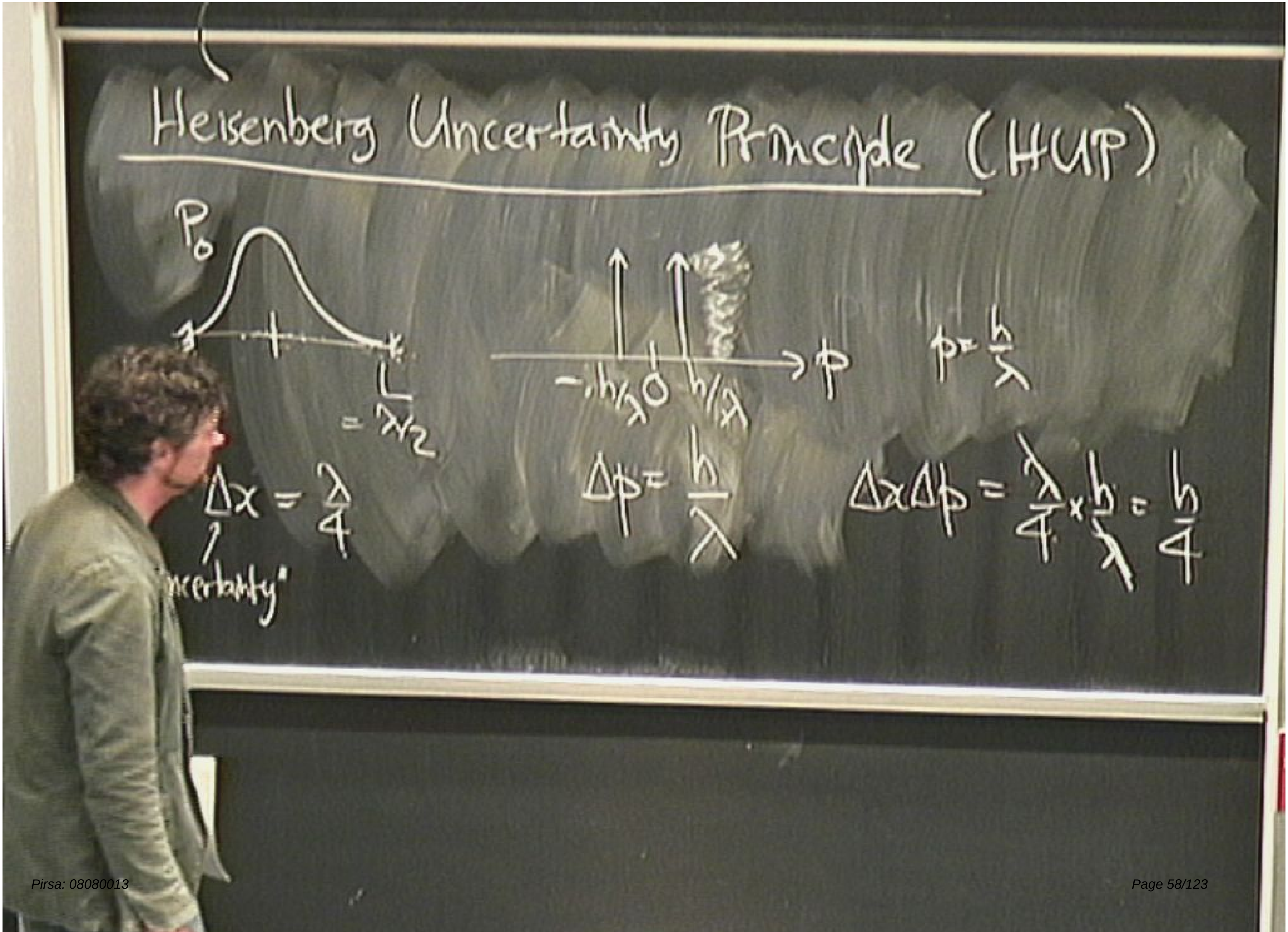

Heisenberg Uncertainty Principle (HUP)
P_0
0
L
= λ/2
0
p
Δx = λ/4
"uncertainty"

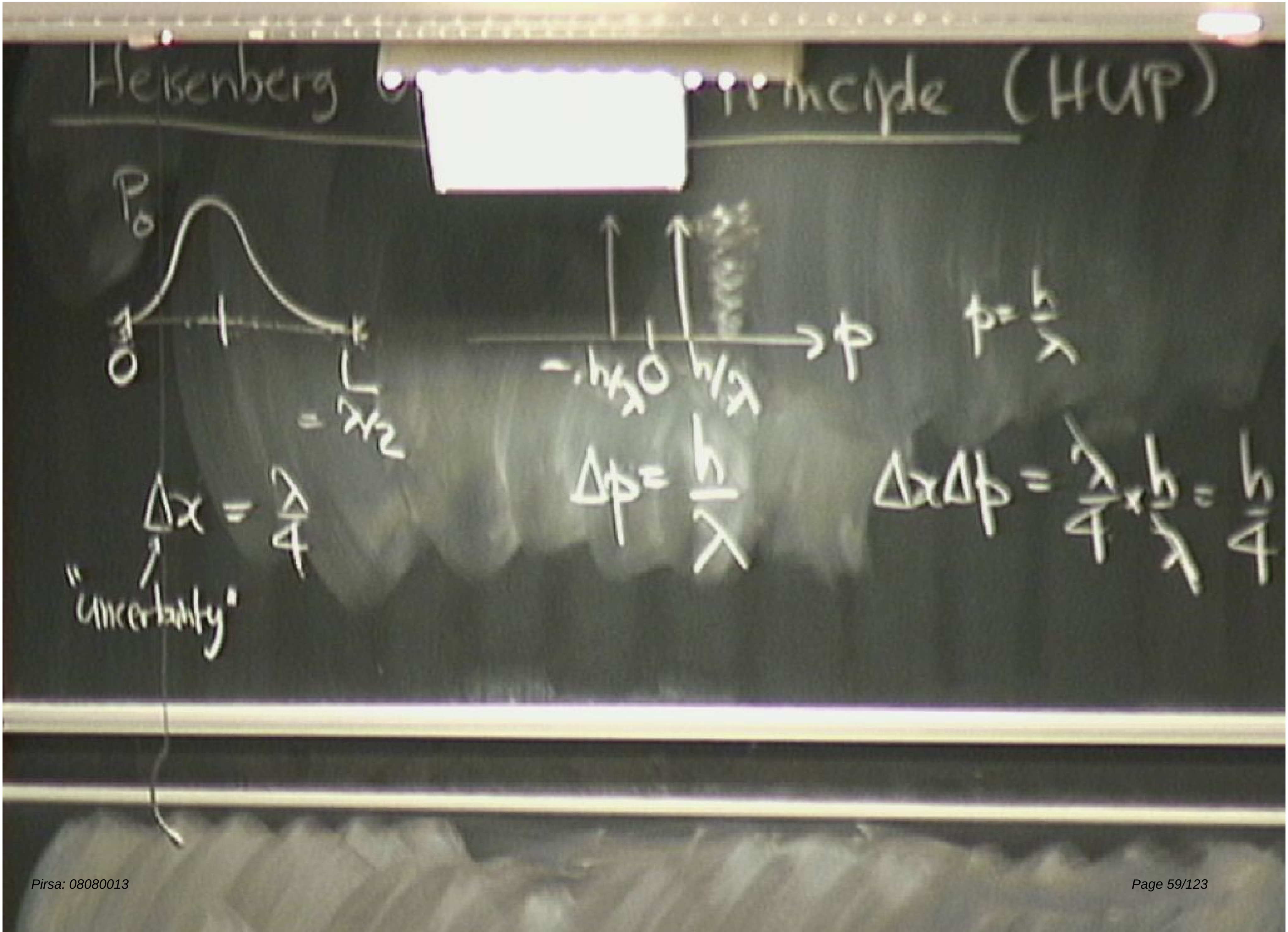

Heisenberg Uncertainty Principle (HUP)
P₀
0
L
= λ/2
Δx = λ/4
"uncertainty"
-λ/h
0
λ/h
p
p = h/λ


classical
E = p^2/2m
+p OR −p
p = ±√2mE
quantum
λ
+p AND −p

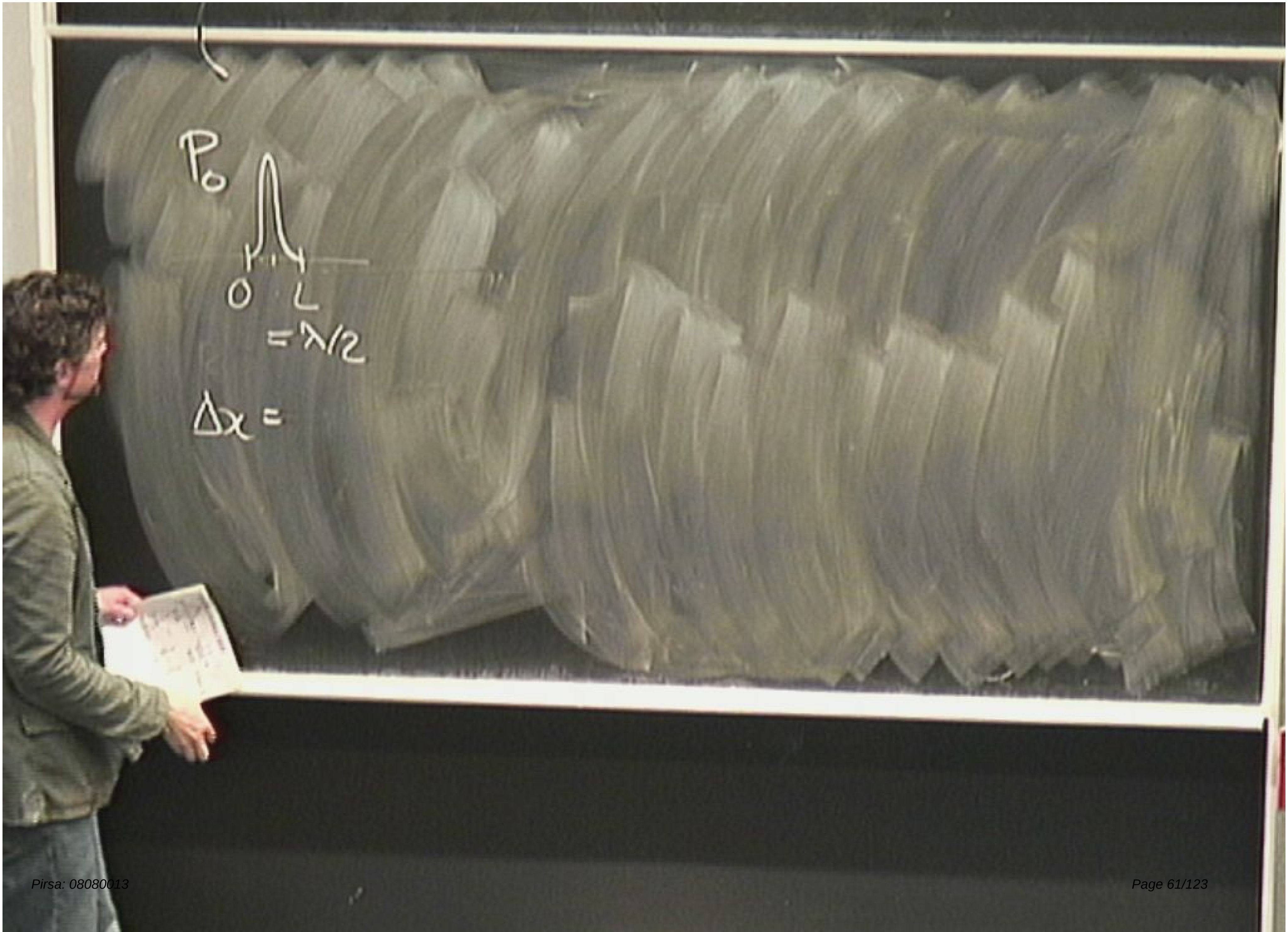

Heisenberg Uncertainty Principle (HUP)
P0
0
L
= λ/2
Δx = λ/4
"uncertainty"
-λ/h 0 λ/h
p
p = h/λ
Δp = λ/h

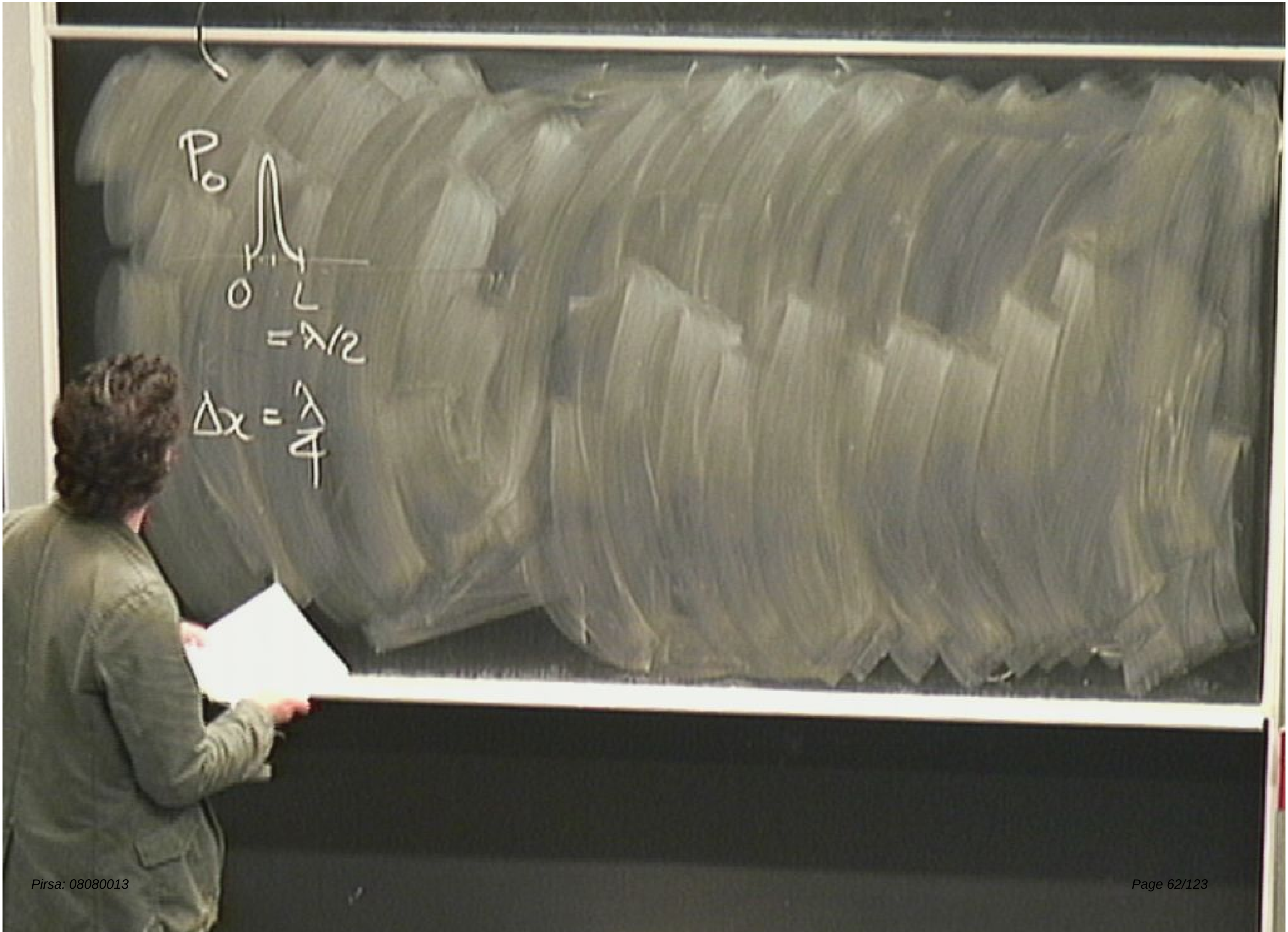

Heisenberg Uncertainty Principle (HUP)
P_0
0
L
$= \lambda/2$
$\Delta x = \frac{\lambda}{4}$
"uncertainty"
$-h/\lambda$ 0 h/λ
p
$p = \frac{h}{\lambda}$
$\Delta p = \frac{h}{\lambda}$

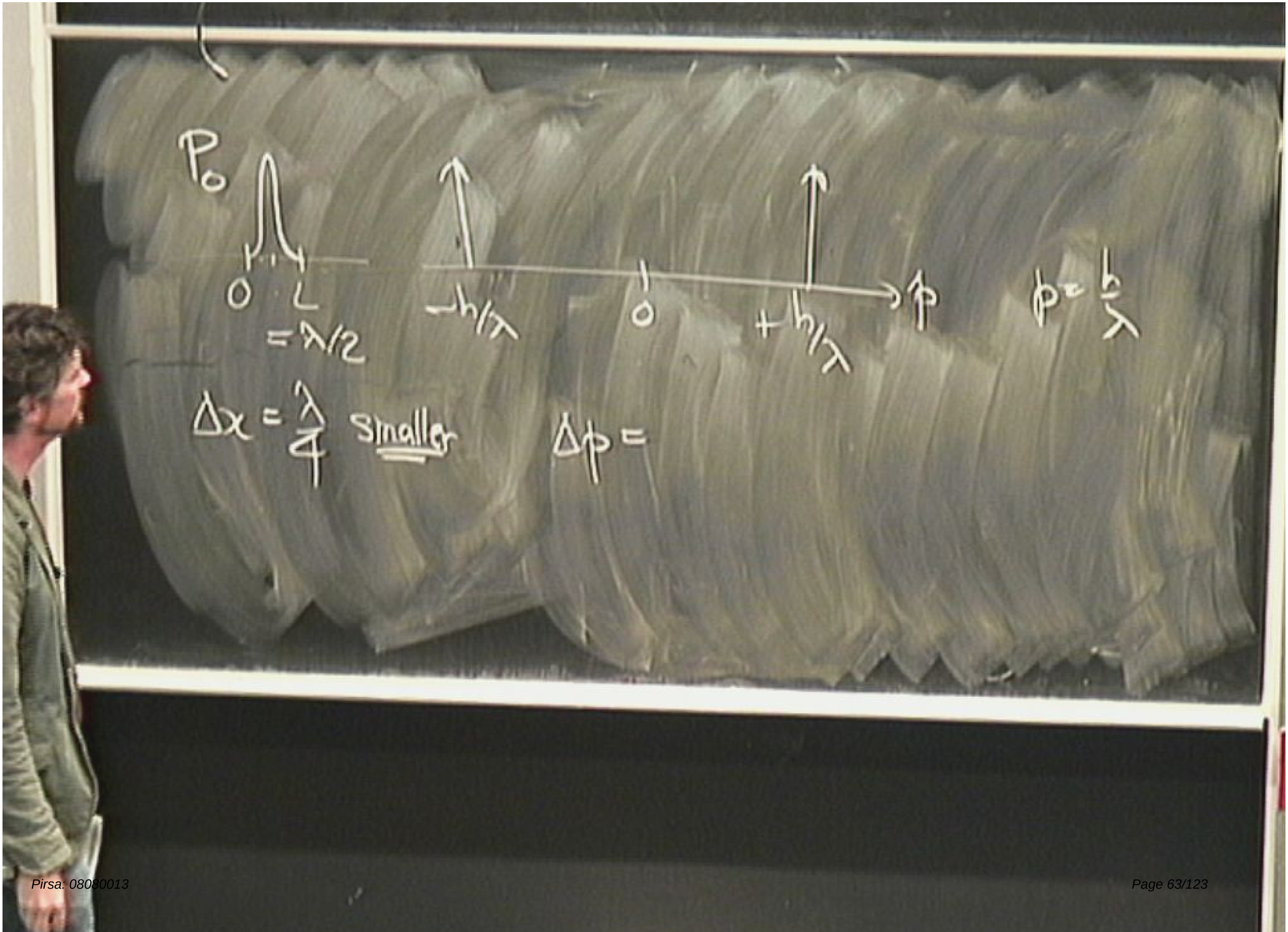

Heisenberg Uncertainty Principle (HUP)
P_0
L
$= \lambda/2$
$-h/\lambda$ 0 h/λ
p
$p = \frac{h}{\lambda}$
$\Delta x = \frac{\lambda}{4}$
"uncertainty"
$\Delta p = \frac{h}{\lambda}$
$\Delta x \Delta p = \frac{\lambda}{4} \times \frac{h}{\lambda} = \frac{h}{4}$

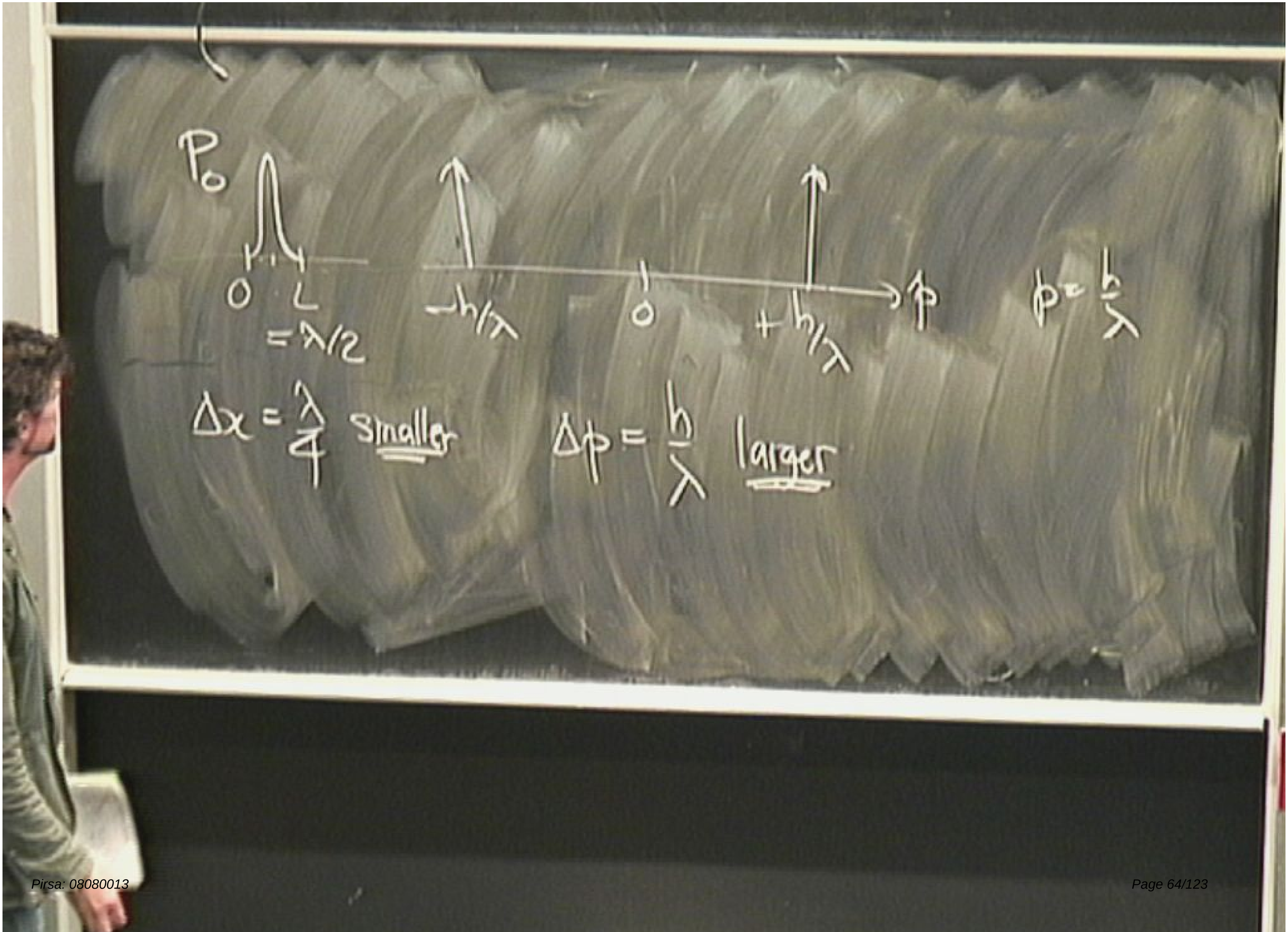

Heisenberg … rinciple (HUP)
P0
0
L
= λ/2
Δx = λ/4
"uncertainty"
-h/λ 0 h/λ
p
Δp = h/λ
p = h/λ
ΔxΔp = λ/4 × h/λ = h/4

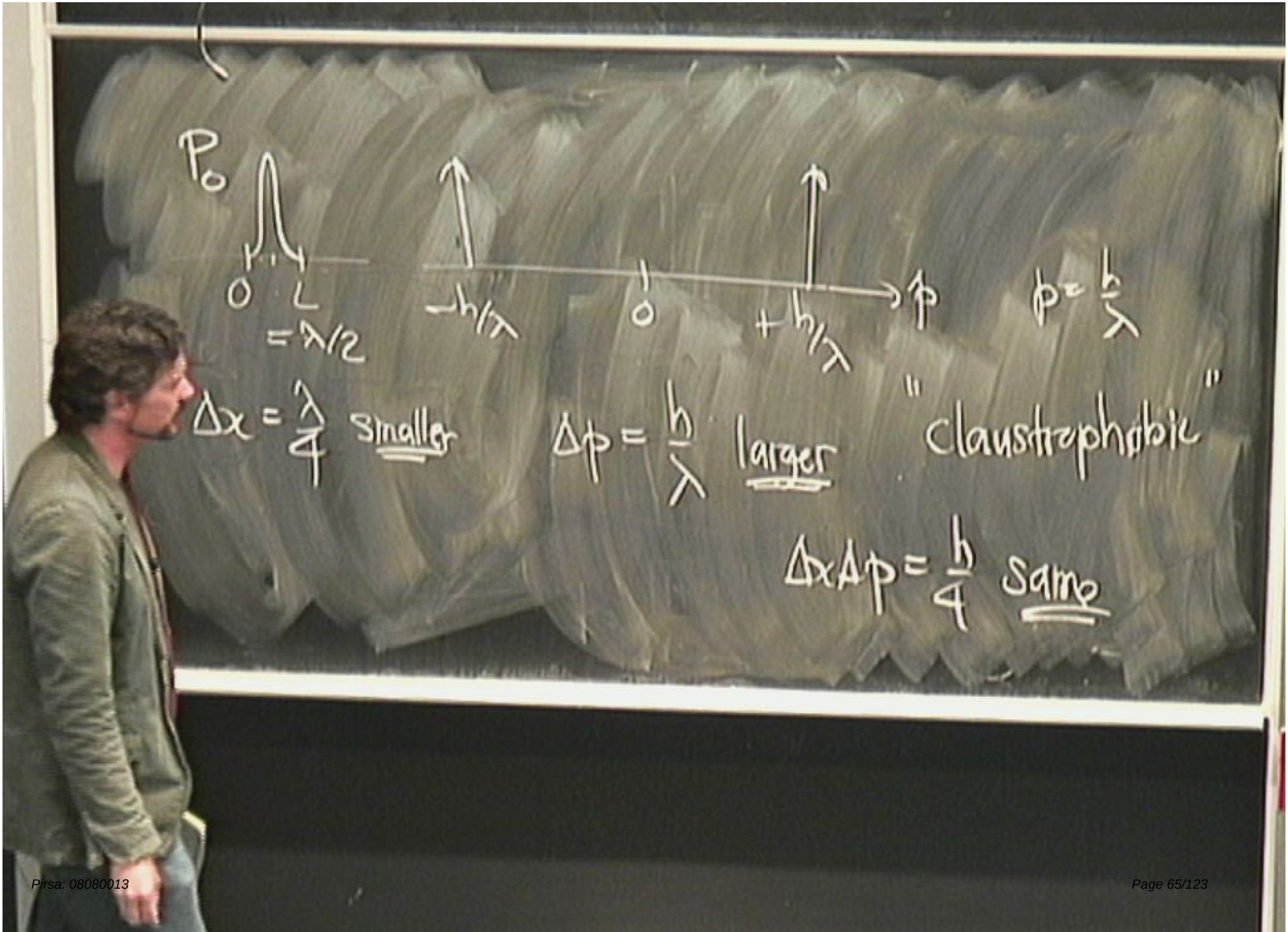

P0
0
L

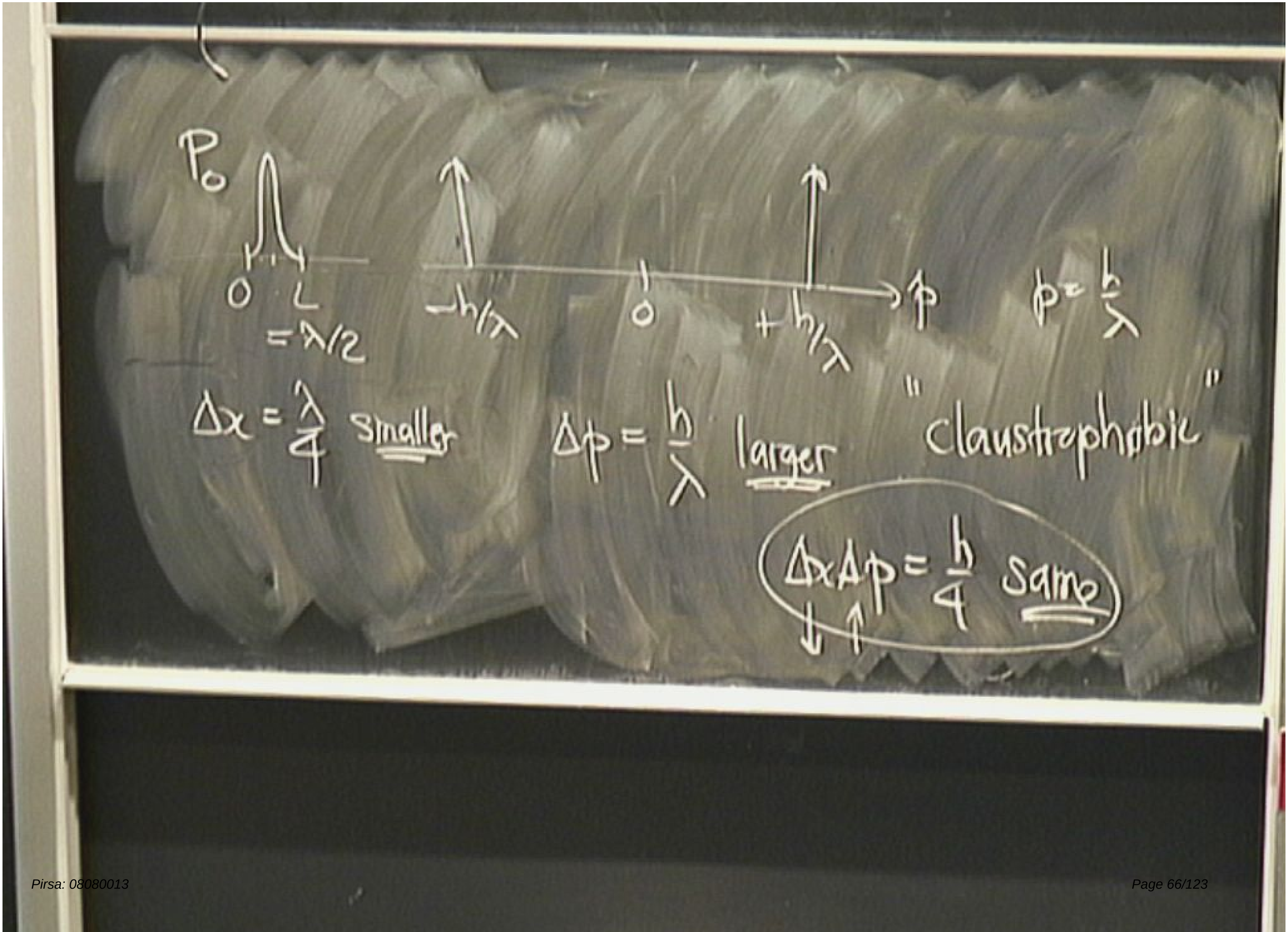

P_0
0 L
$= \lambda/2$
$\Delta x =$

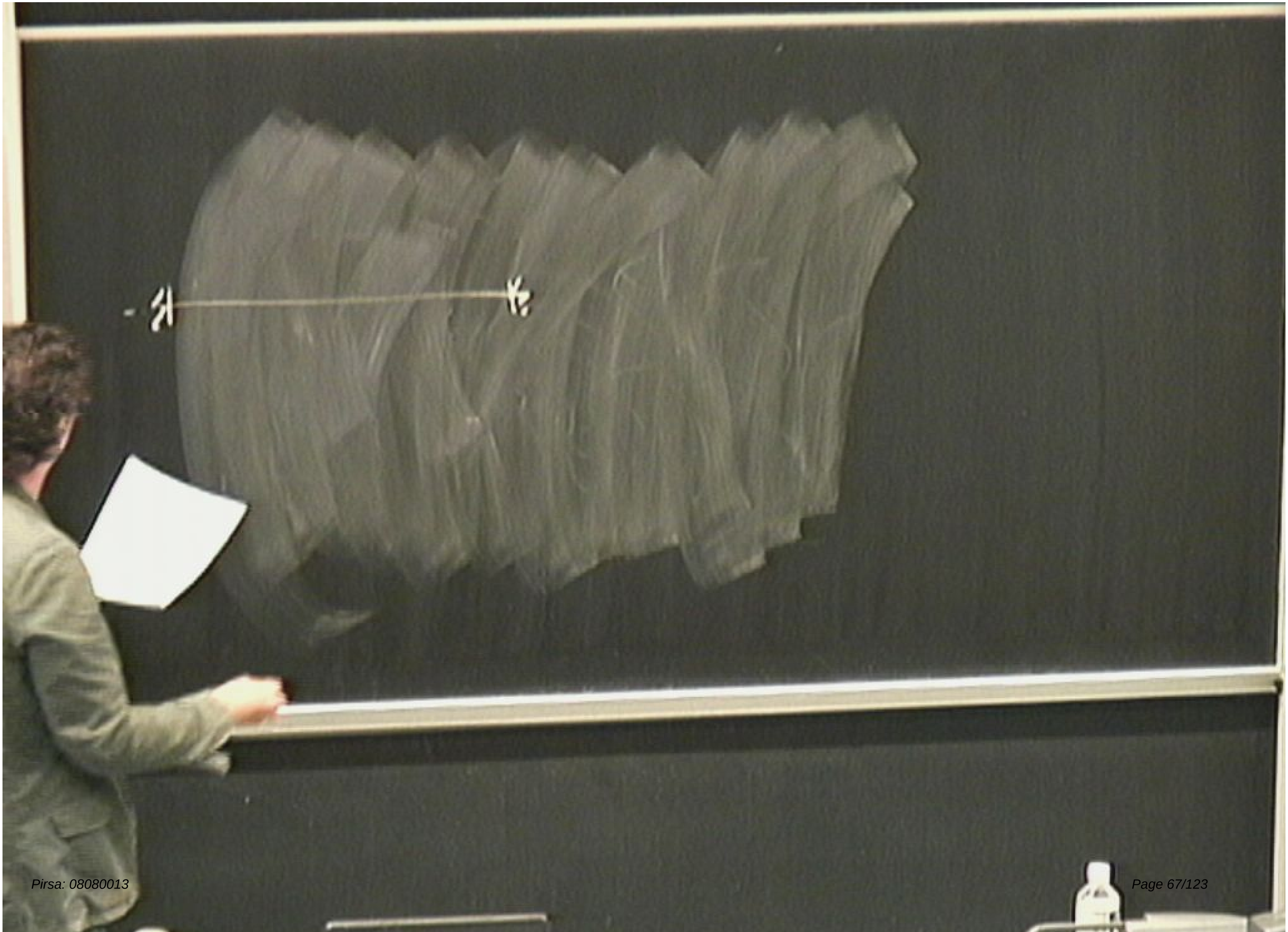

P0
0 L
= λ/2
Δx = λ/4

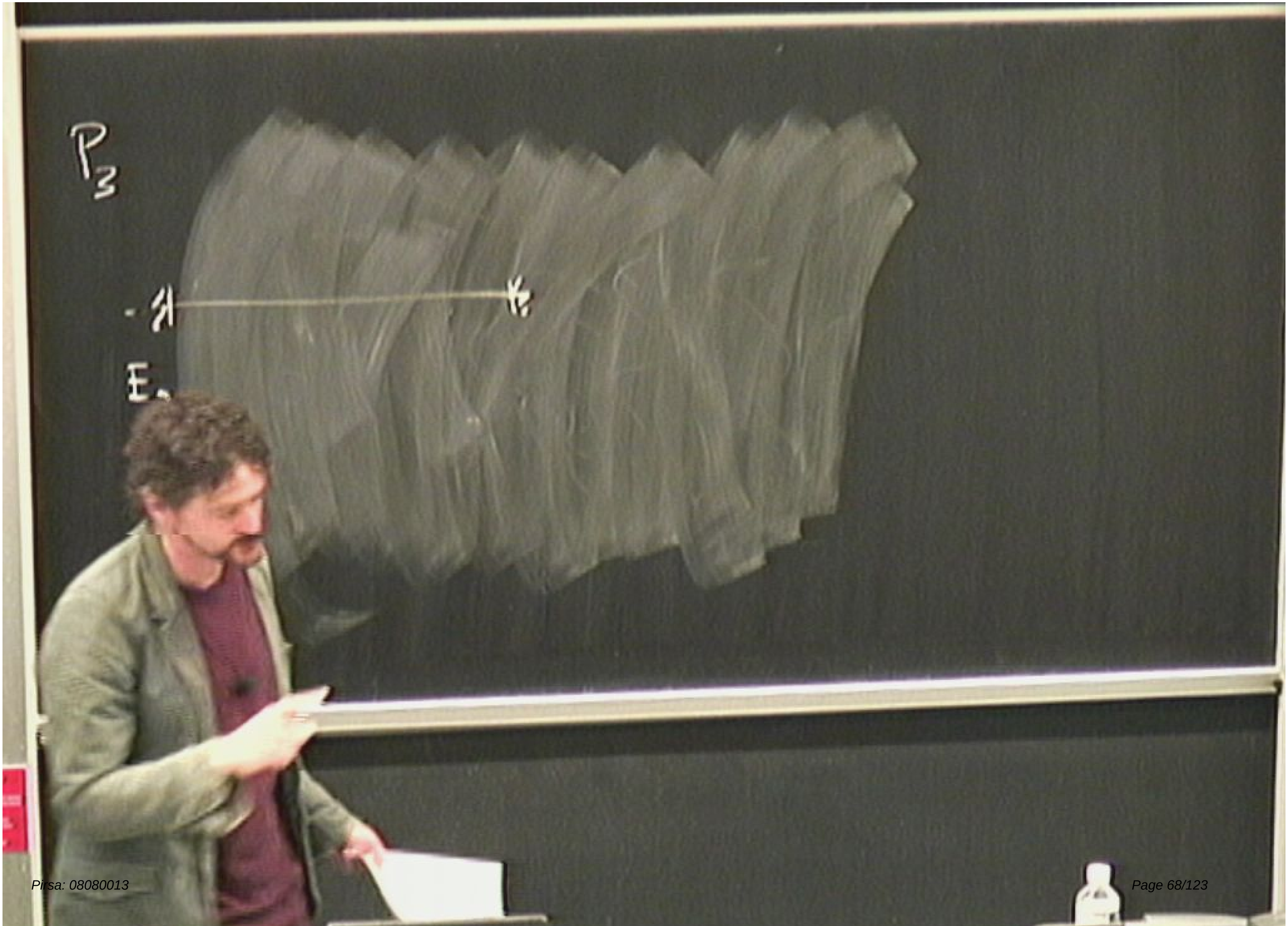

P0
0 L
= λ/2
-h/T
0
+h/T
p
p = h/λ
Δx = λ/4 smaller
Δp =

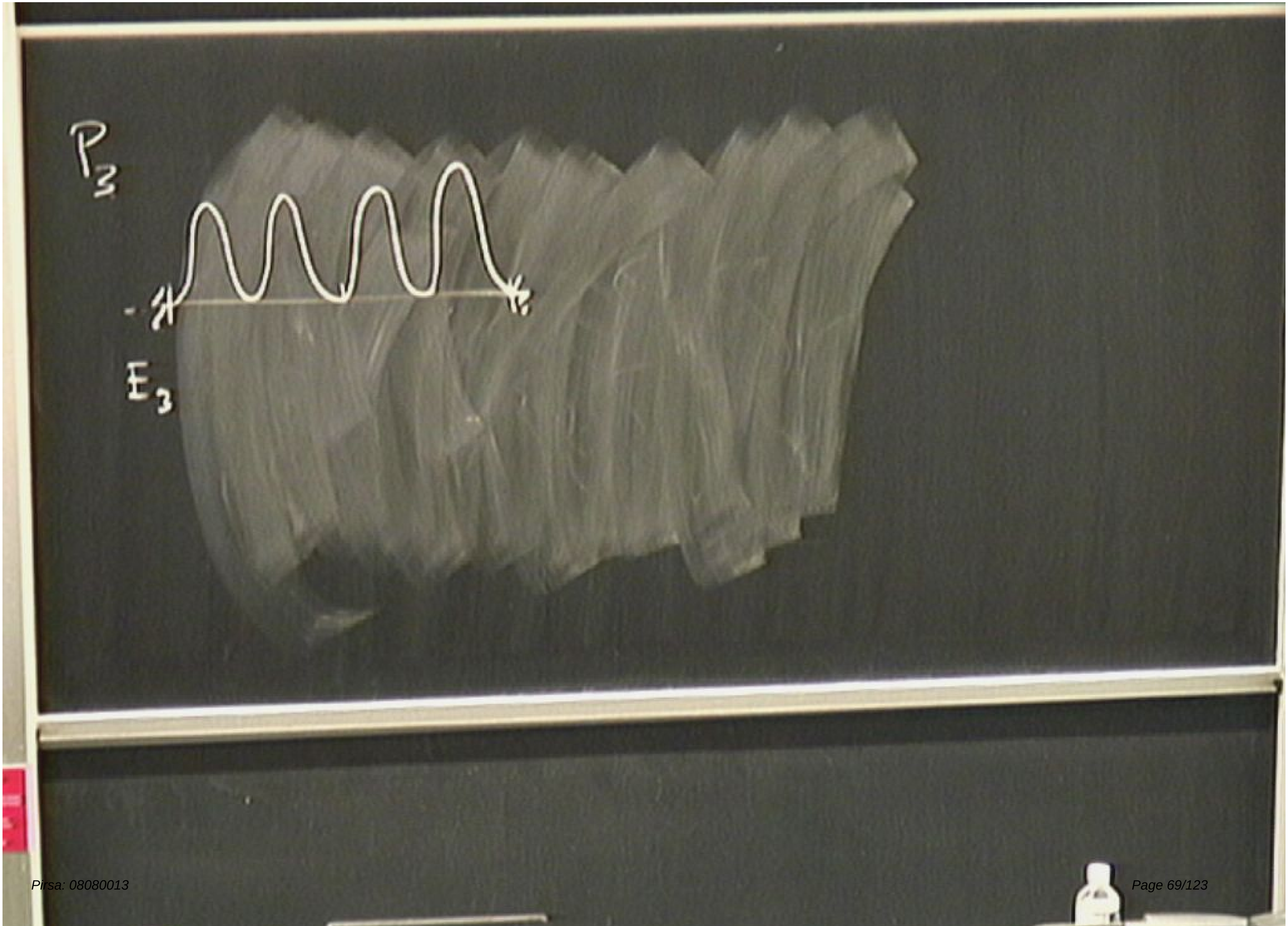

P0
0
L
=λ/2
-h/λ
0
+h/λ
p
p = h/λ
Δx = λ/4 smaller
Δp = h/λ larger

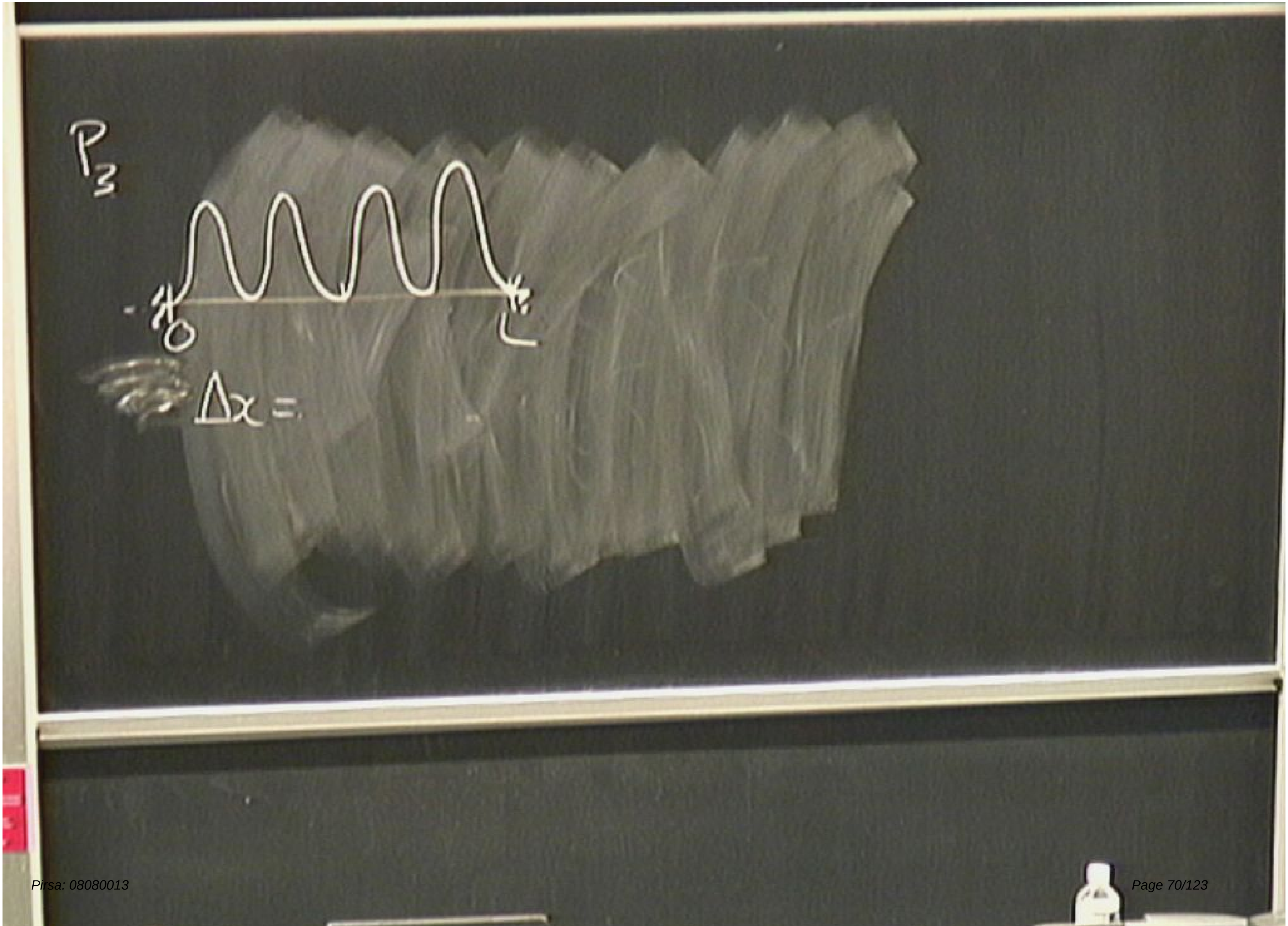

P0
0 L
= λ/2
−h/T
0
+h/T
p
p = h/λ
Δx = λ/4 smaller
Δp = h/λ larger
"Claustrophobic"
ΔxΔp = h/4 same

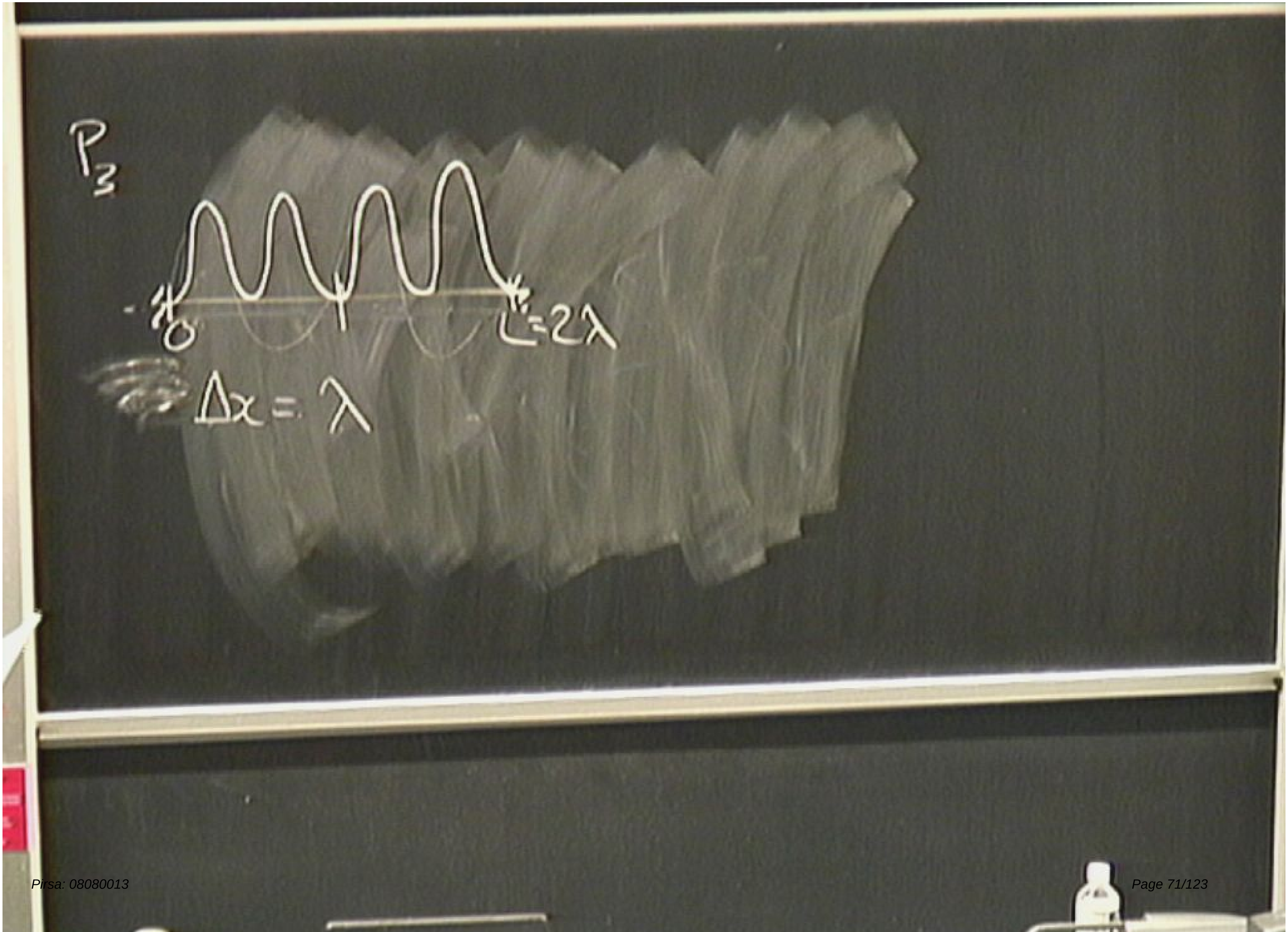

P_0
0 L
$= \lambda/2$
$-h/T$
0
$+h/T$
p
$p = \frac{h}{\lambda}$
$\Delta x = \frac{\lambda}{4}$ smaller
$\Delta p = \frac{h}{\lambda}$ larger
"Claustrophobic"
$\Delta x \Delta p = \frac{h}{4}$ same

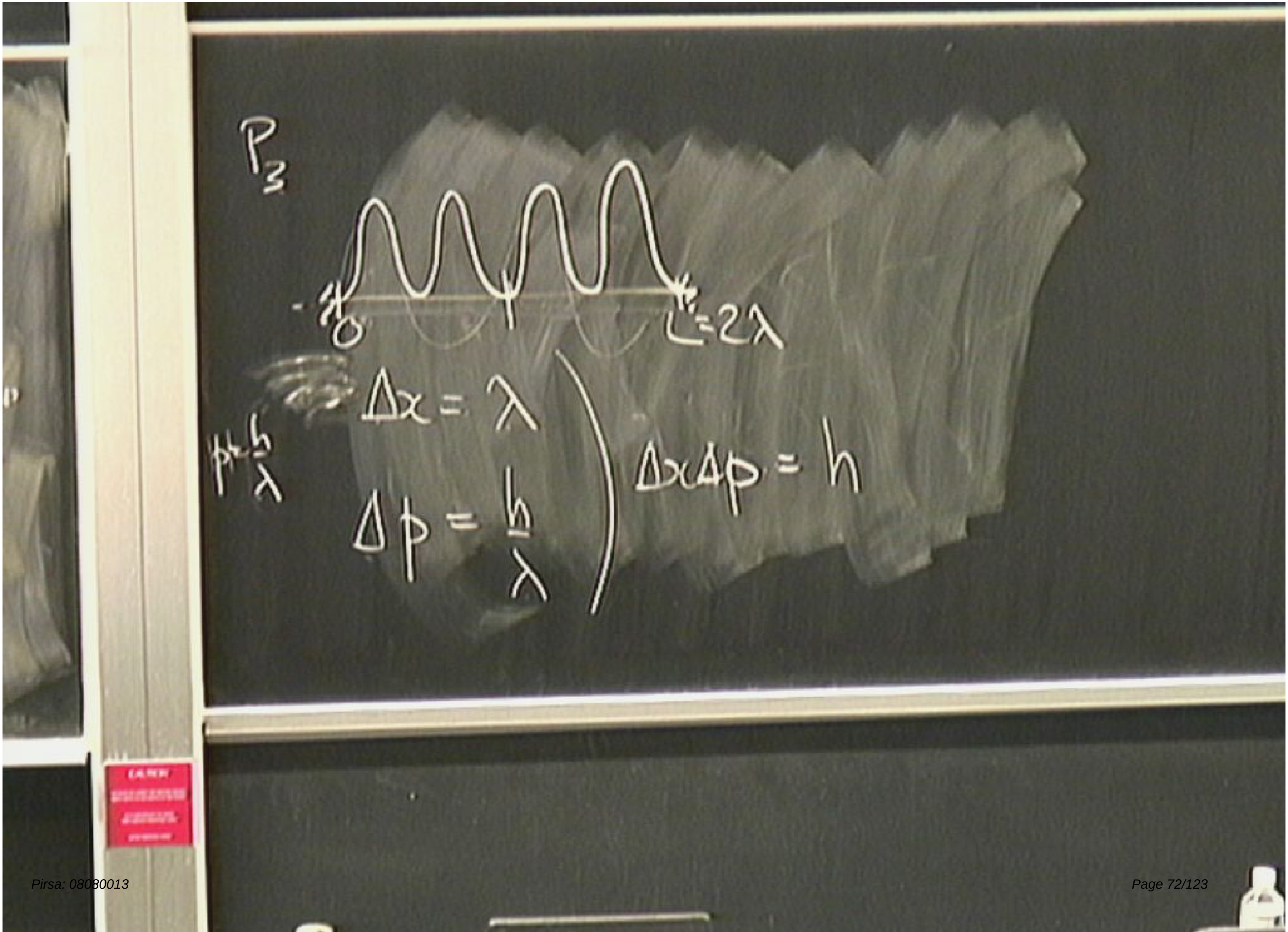


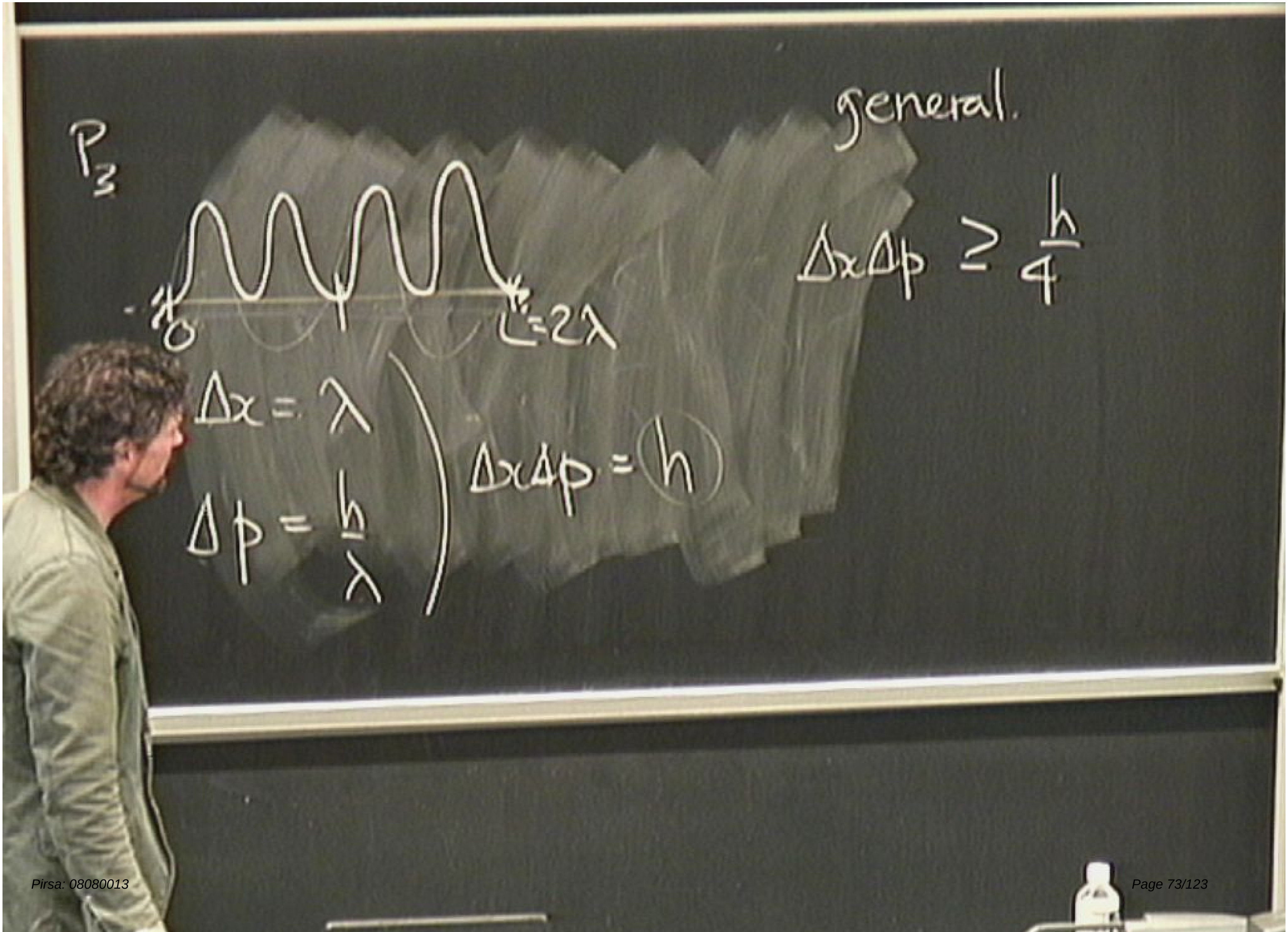

P3

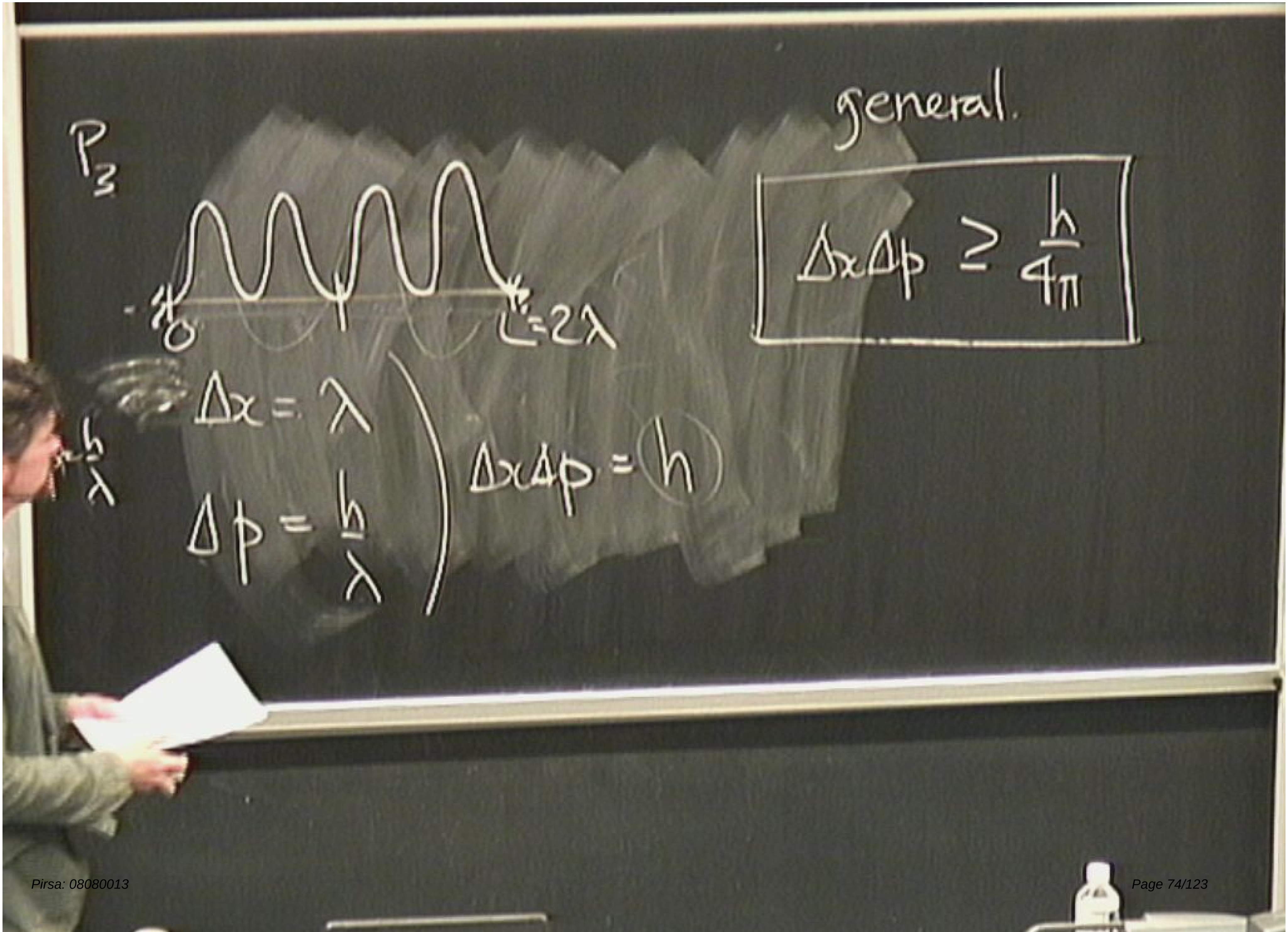

P3
E3

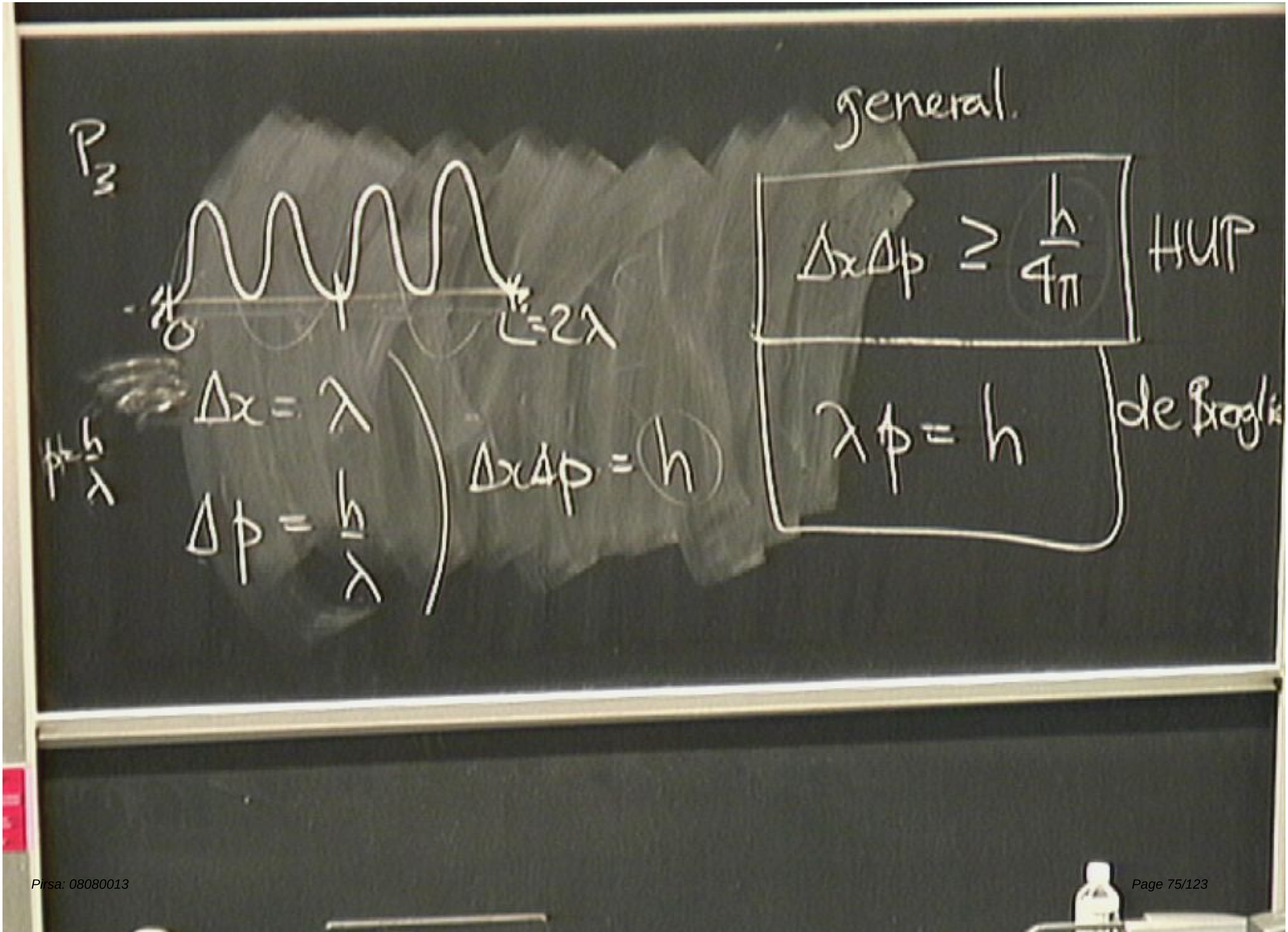

P3
0
L
Δx =

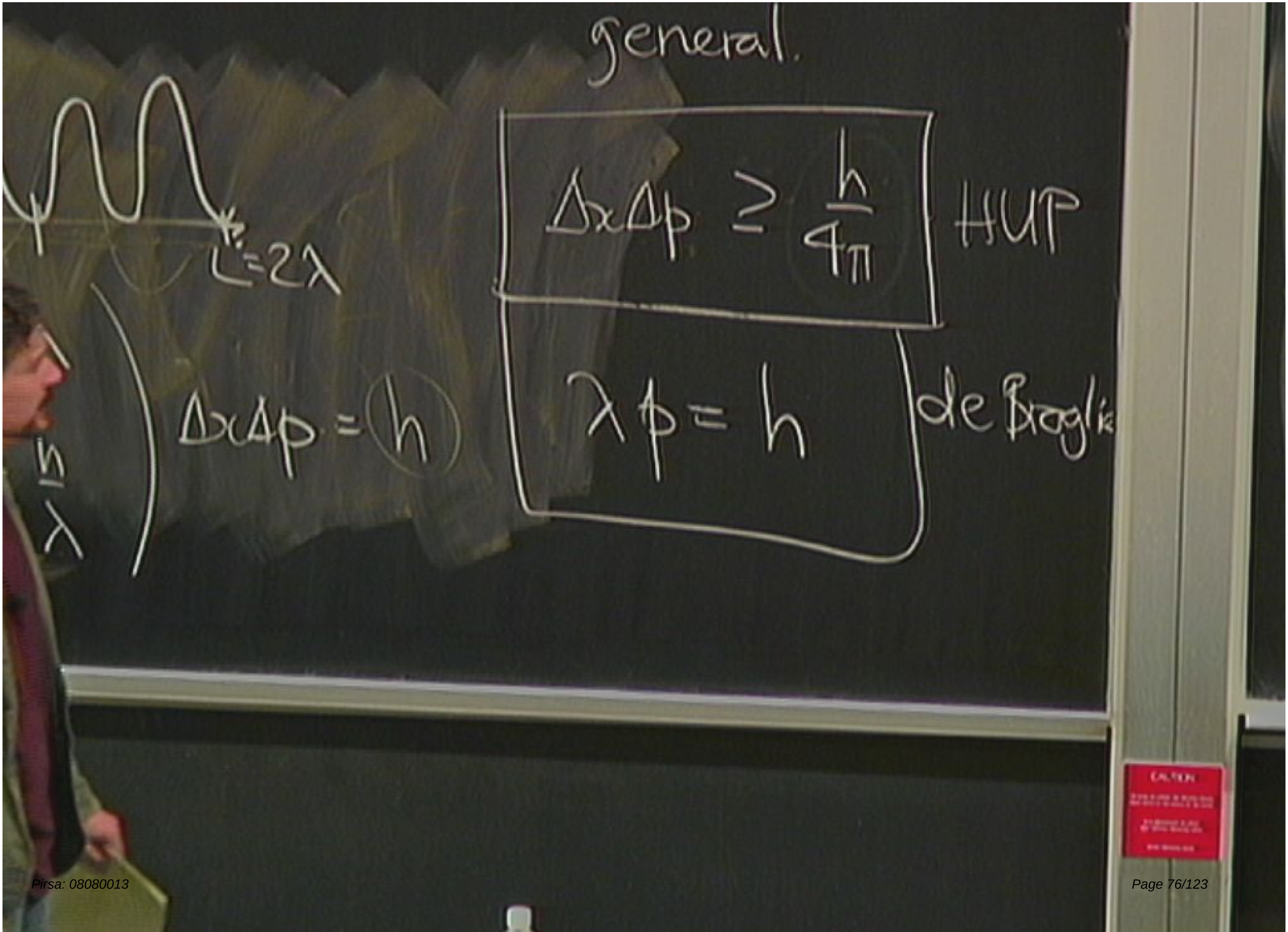

P3
0
L=2λ
Δx = λ


P3
0
L=2λ
Δx = λ
p = h/λ
Δp = h/λ
ΔxΔp = h


P3
general.
ΔxΔp ≥ h/4
0
L=2λ
Δx = λ
Δp = h/λ
ΔxΔp = h


P3
general.
ΔxΔp ≥ h/4π
0
L=2λ
Δx = λ
Δp = h/λ
ΔxΔp = h


P3
general.
ΔxΔp ≥ h/4π
HUP
λp = h
de Broglie
0
L=2λ
p=h/λ
Δx = λ
Δp = h/λ
ΔxΔp = h


general.
L=2λ
ΔxΔp ≥ h/4π
HUP
ΔxΔp = h
λp = h
de Broglie
h/λ

"Strong" Interpretation of HUP

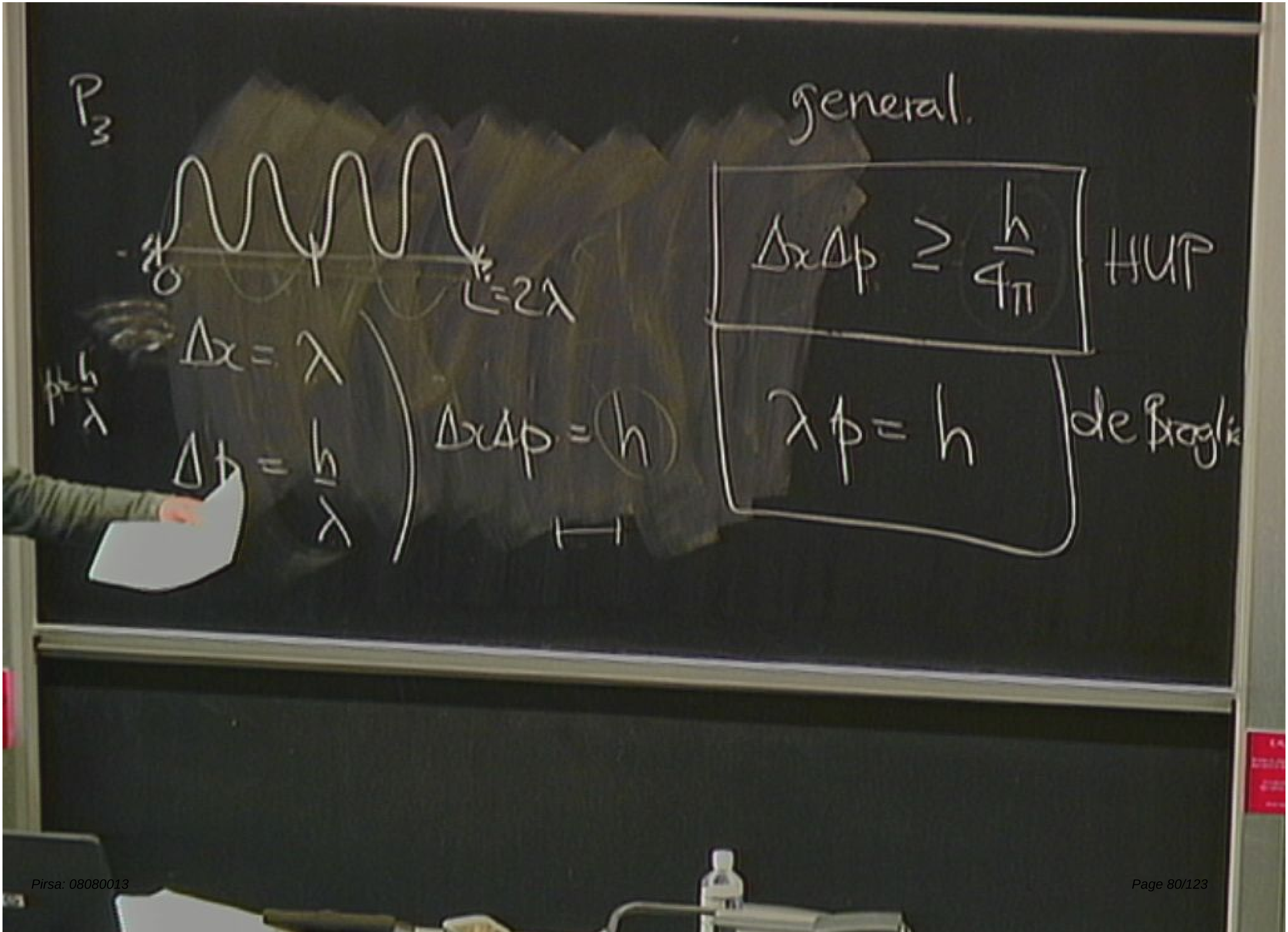
"Strong" Interpretation of HUP

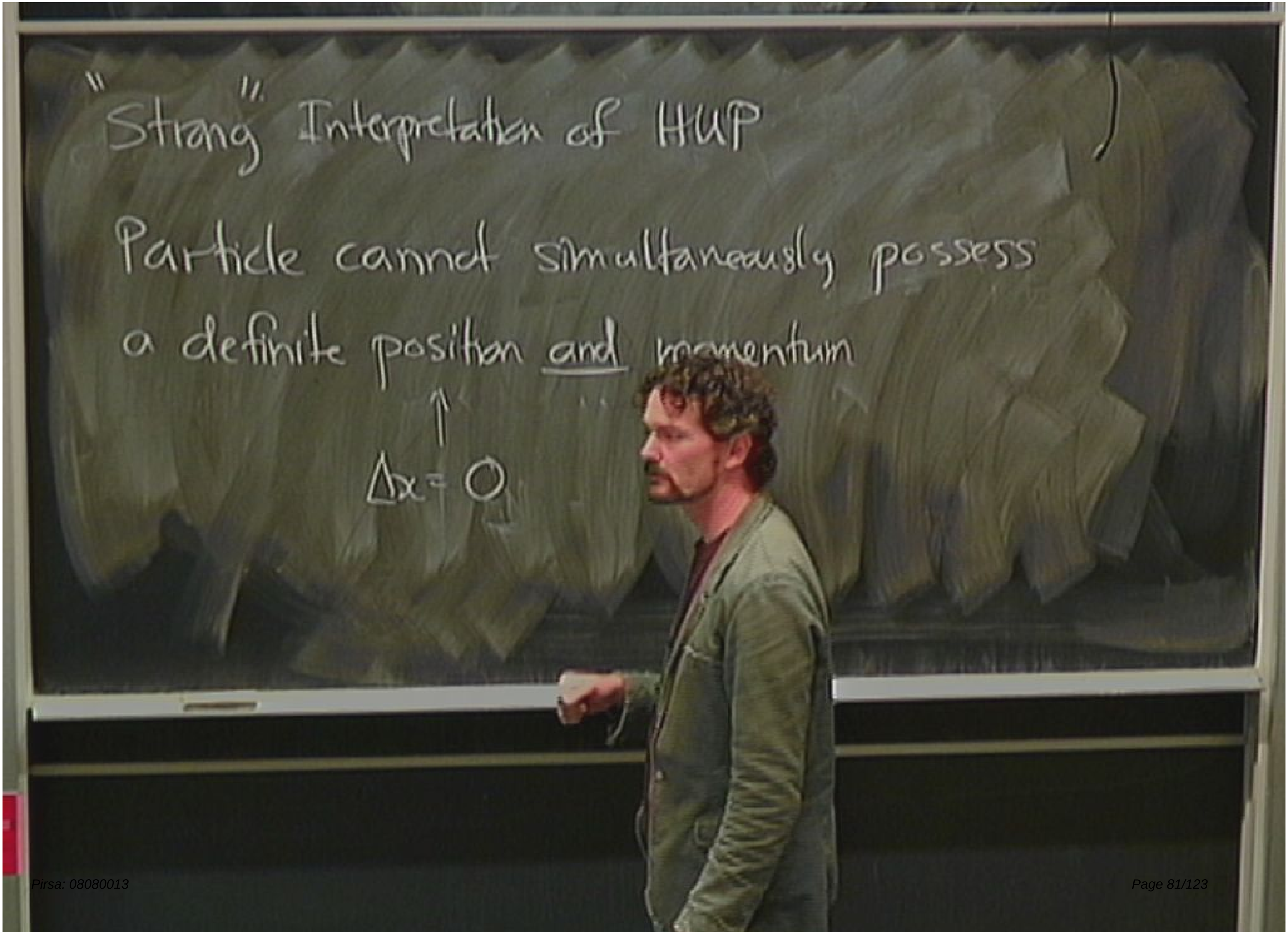
Particle cannot simultaneausly possess a definite position <u>and</u> momentum

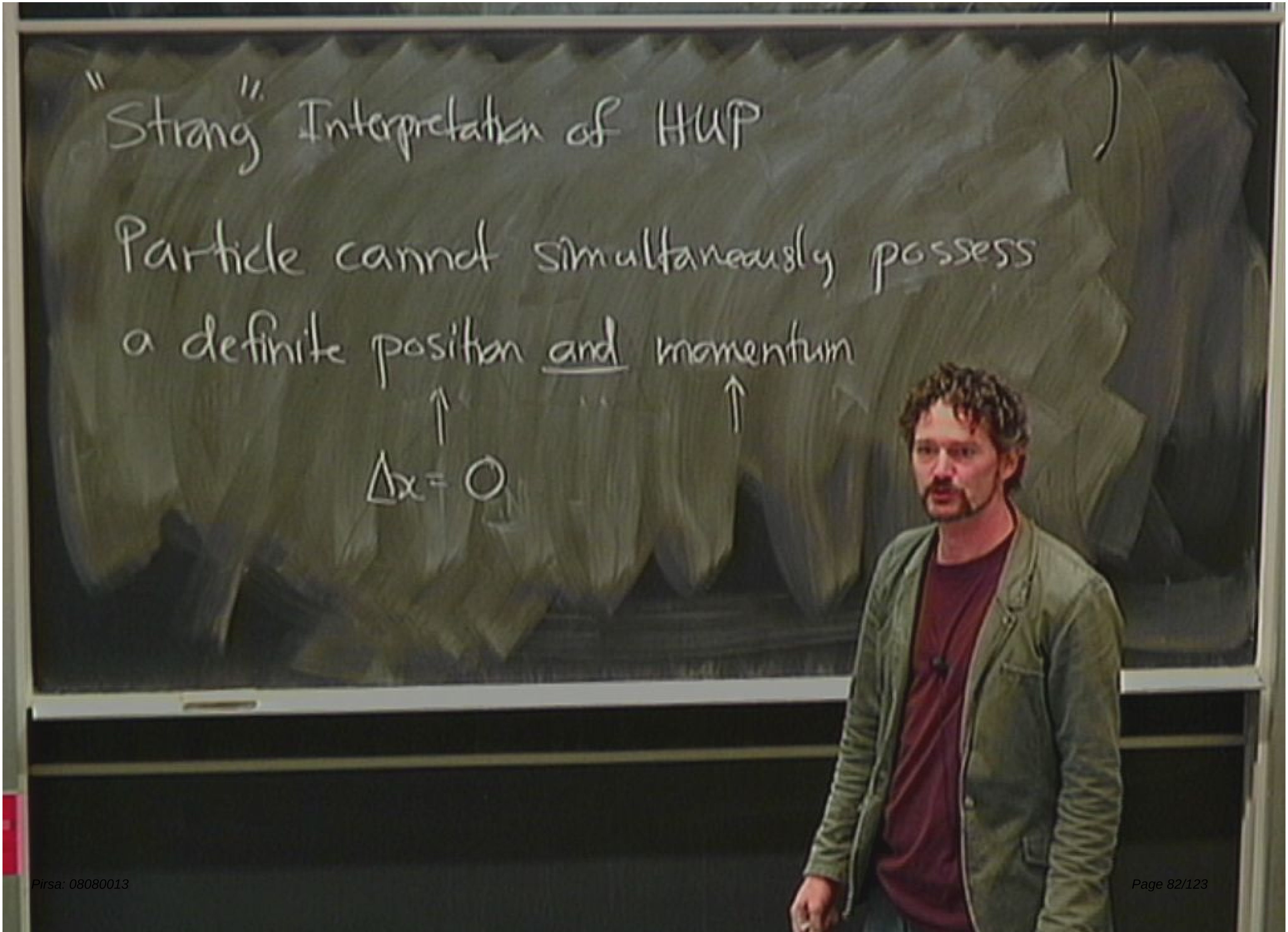
"Strong" Interpretation of HUP

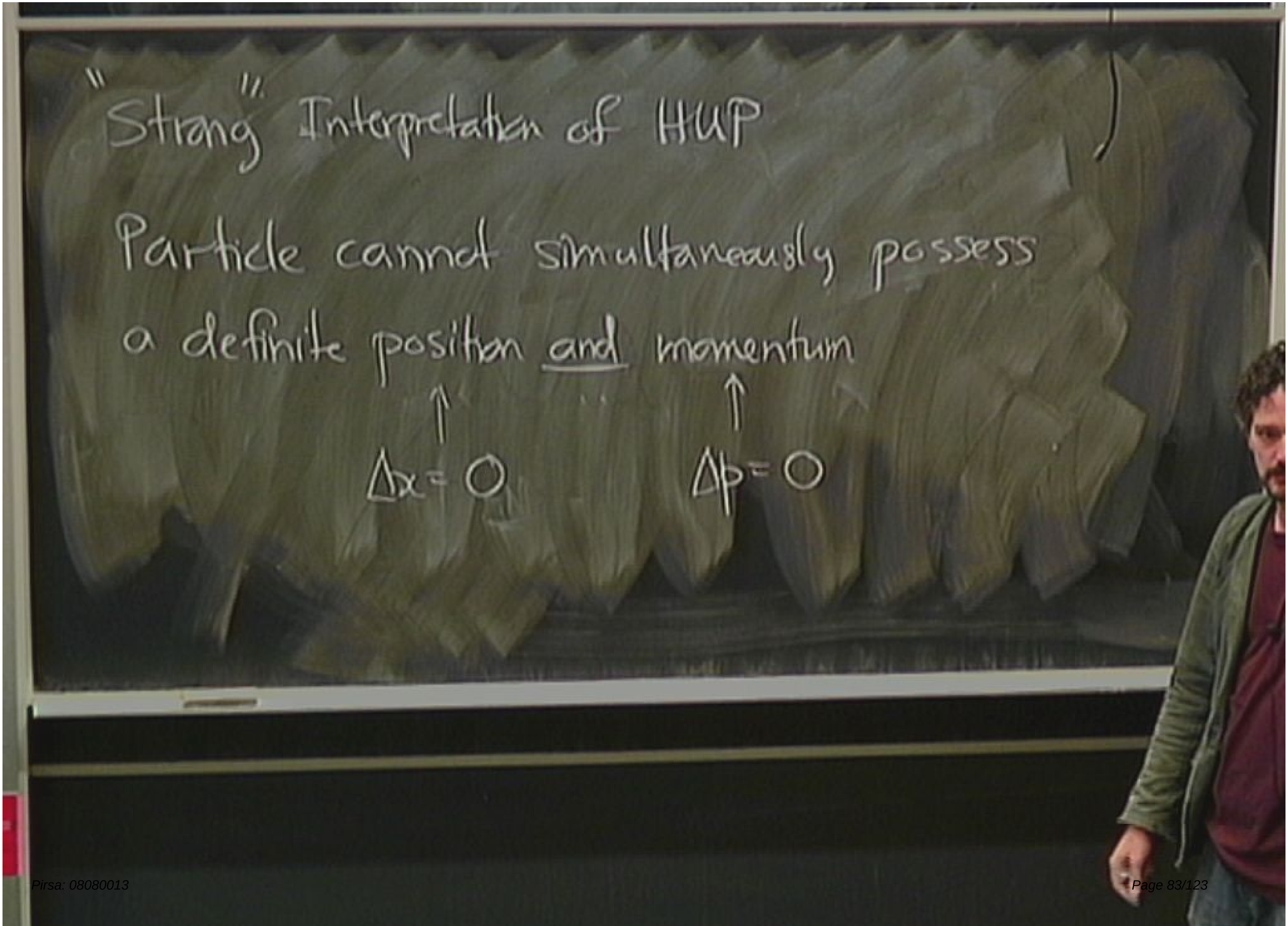
Particle cannot simultaneously possess a definite position <u>and</u> momentum

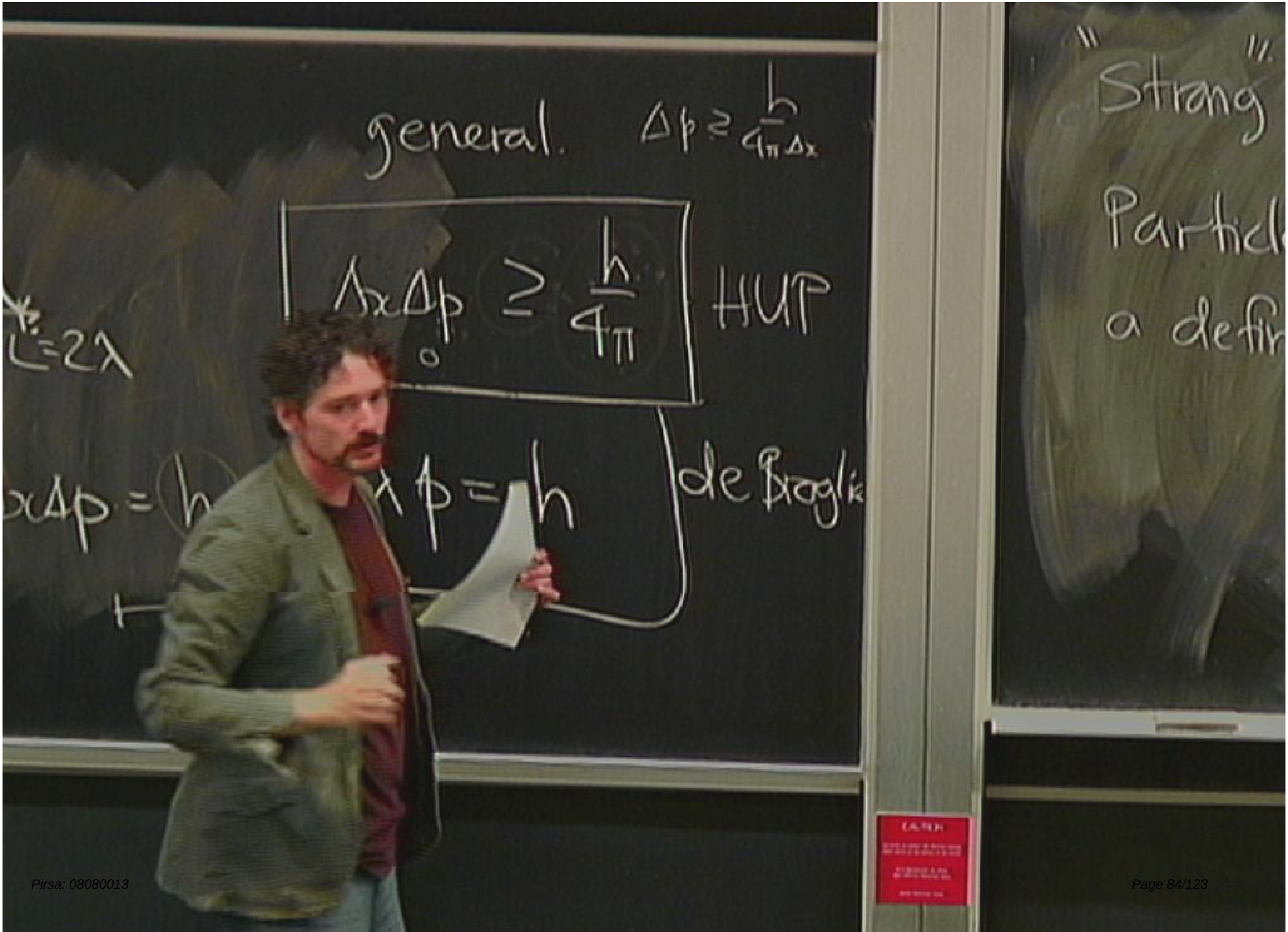
↑

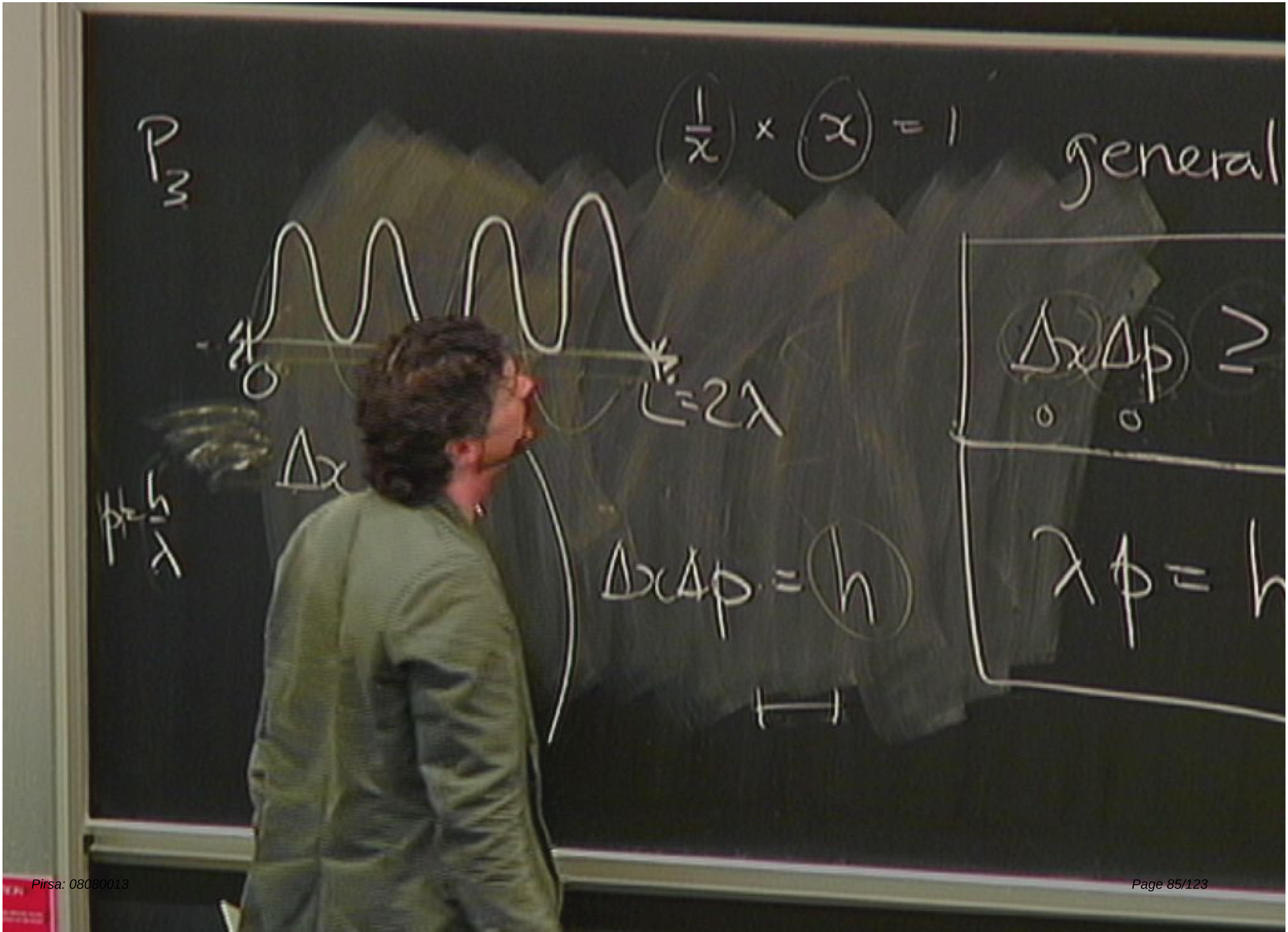

P3
general.
ΔxΔp ≥ h/4π
HUP
λp = h
de Broglie
0
L=2λ
Δx = λ
p = h/λ
Δp = h/λ
ΔxΔp = h


"Strong" Interpretation of HUP
Particle cannot simultaneously possess
a definite position and momentum
Δx = 0

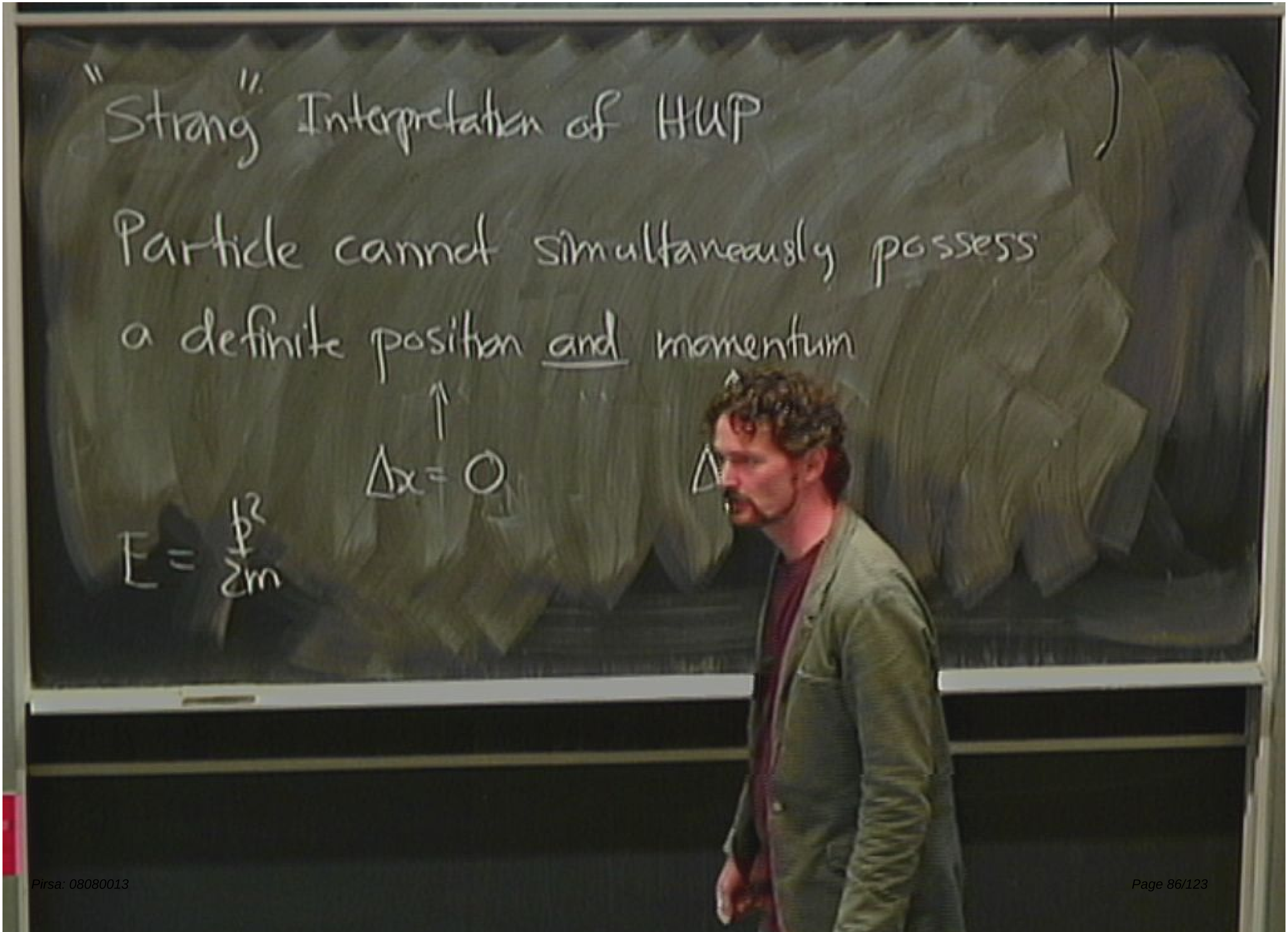

"Strong" Interpretation of HUP
Particle cannot simultaneously possess
a definite position and momentum
Δx = 0

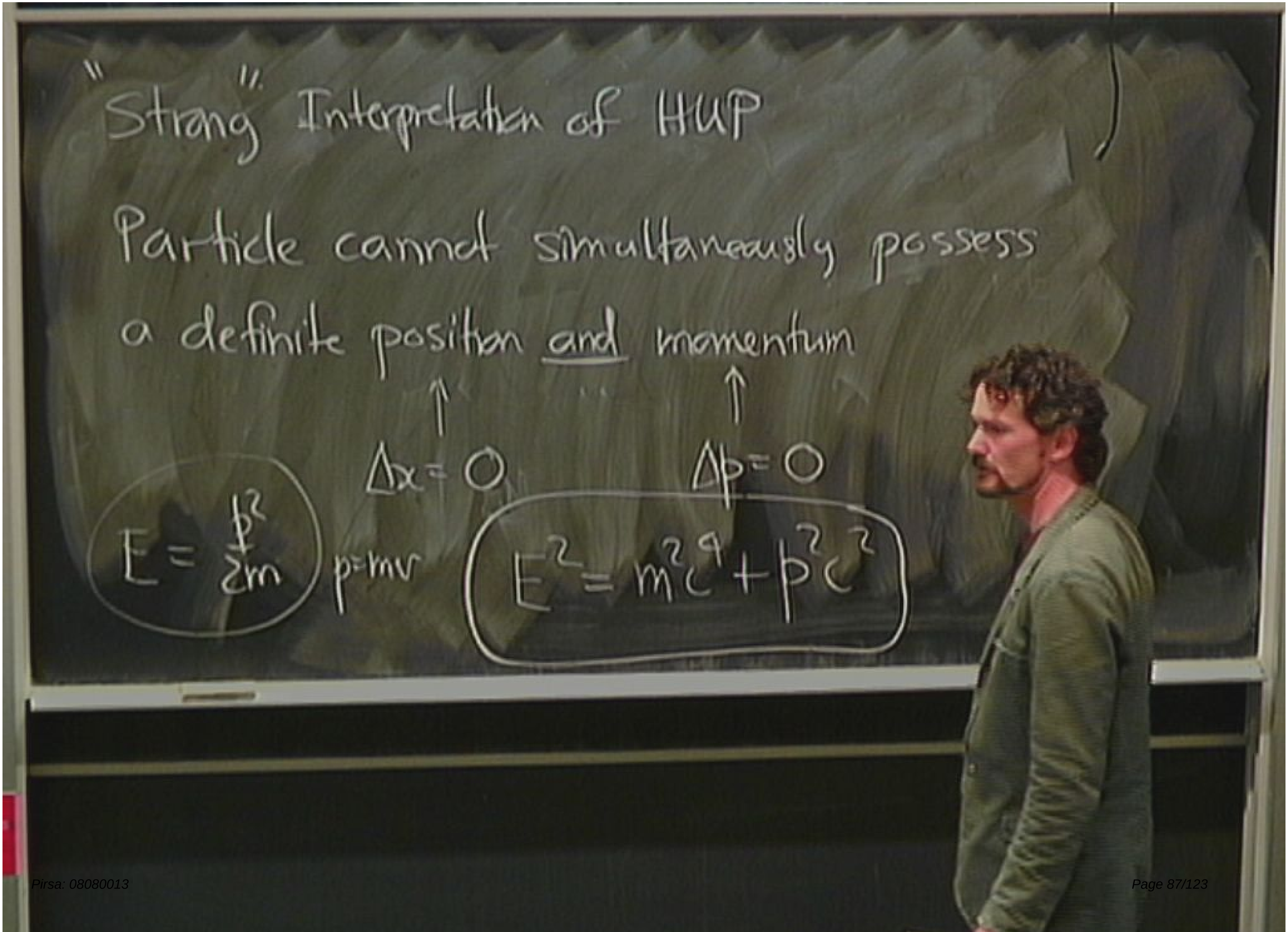

"Strong" Interpretation of HUP
Particle cannot simultaneously possess
a definite position and momentum
Δx = 0
Δp = 0

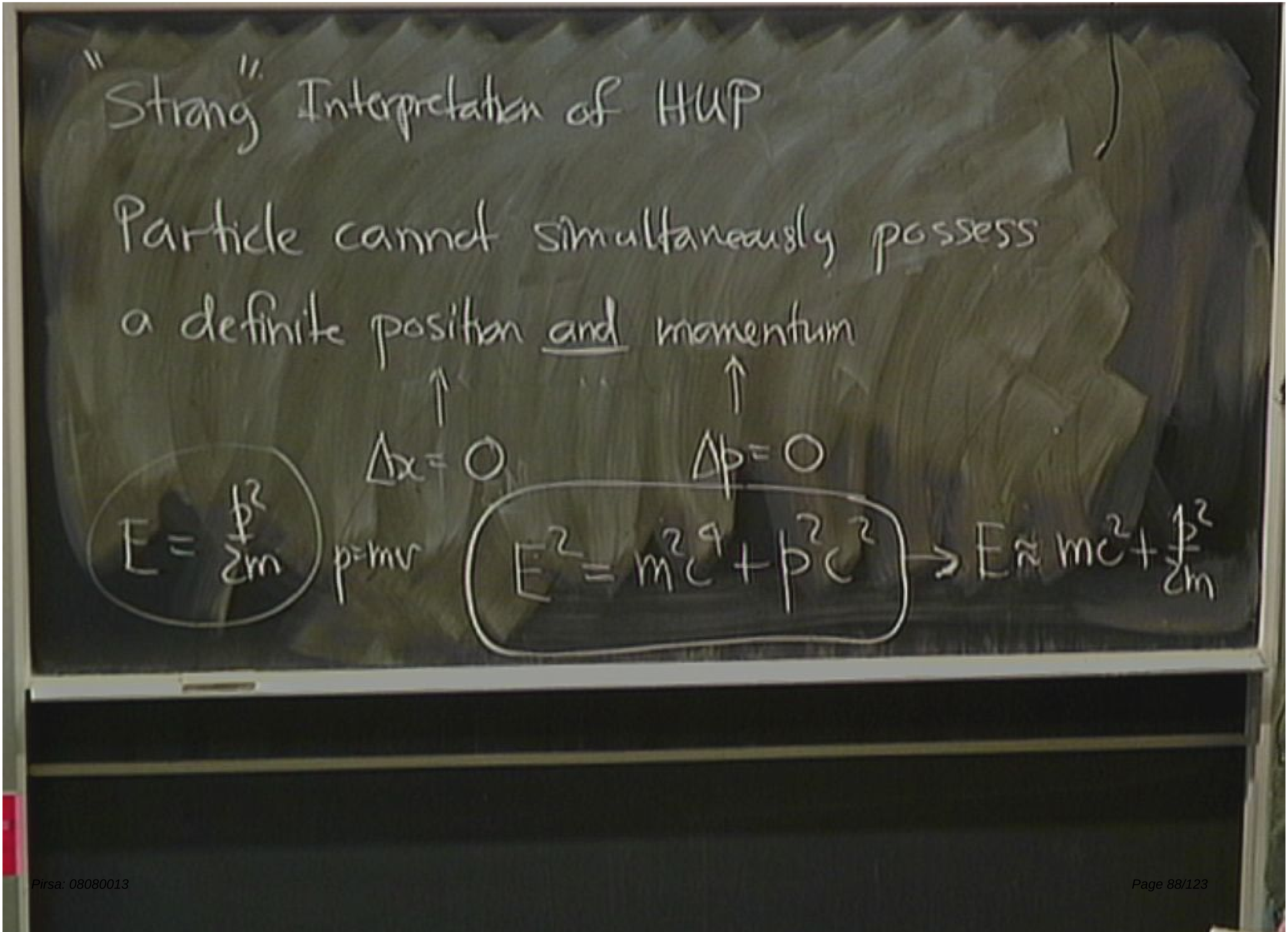

general. Δp ≥ h/4πΔx
ΔxΔp ≥ h/4π
HUP
λp = h
L=2λ
"Strang



P3
1/x × x = 1
general
0
L=2λ
Δx
p=h/λ
ΔxΔp = h
ΔxΔp ≥
λp = h


"Strong" Interpretation of HUP
Particle cannot simultaneously possess
a definite position and momentum
Δx = 0
E = p²/2m


"Strong" Interpretation of HUP
Particle cannot simultaneously possess
a definite position and momentum
Δx = 0
Δp = 0
E = p²/2m
p=mv
E² = m²c⁴ + p²c²


"Strong" Interpretation of HUP
Particle cannot simultaneously possess
a definite position and momentum
$\Delta x = 0$
$\Delta p = 0$
$E = \frac{p^2}{2m}$
$p = mv$
$E^2 = m^2c^4 + p^2c^2$
$\rightarrow E \approx mc^2 + \frac{p^2}{2m}$

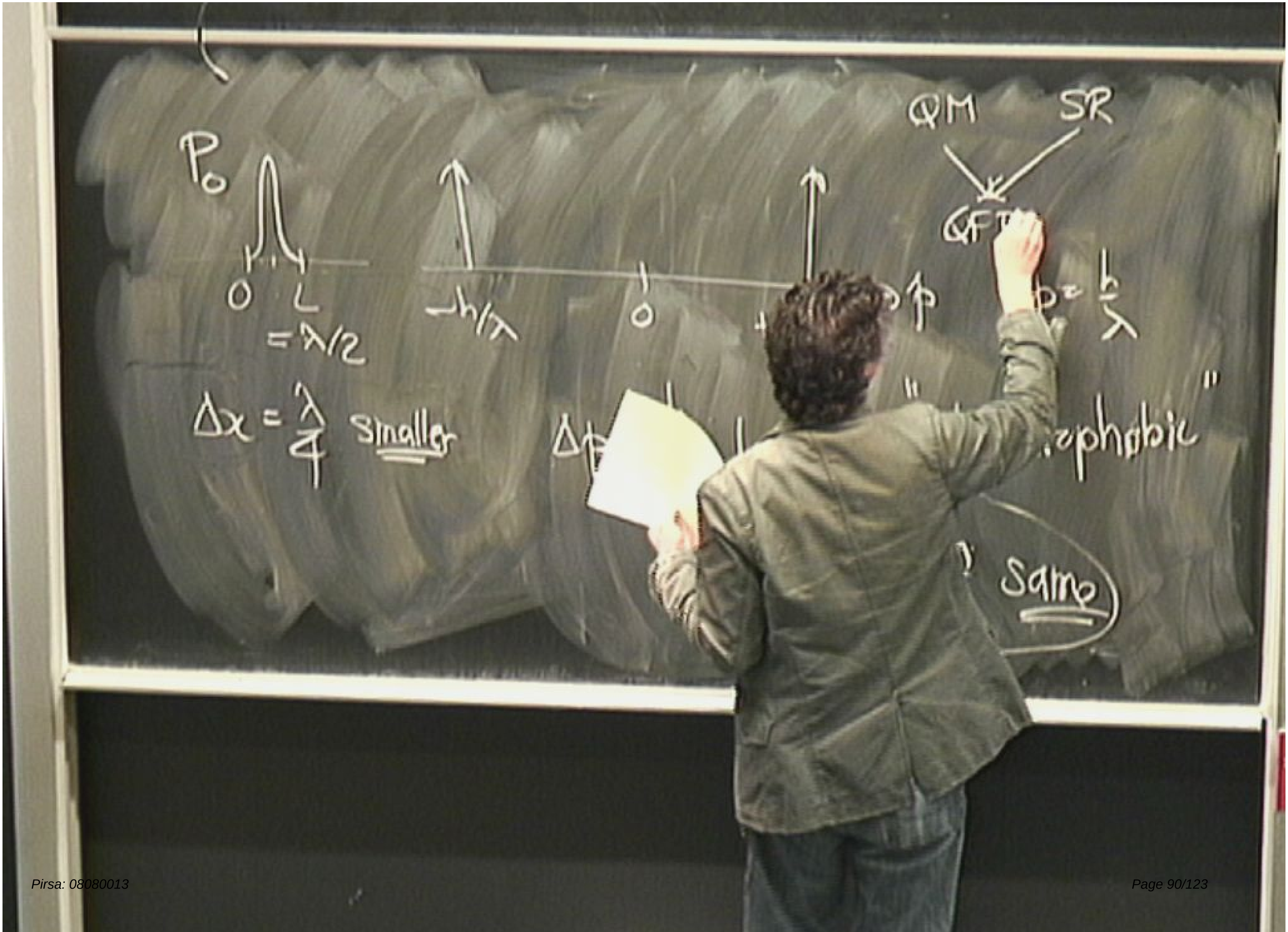
"Strong" Interpretation of HUP

Particle cannot simultaneously possess a definite position <u>and</u> momentum

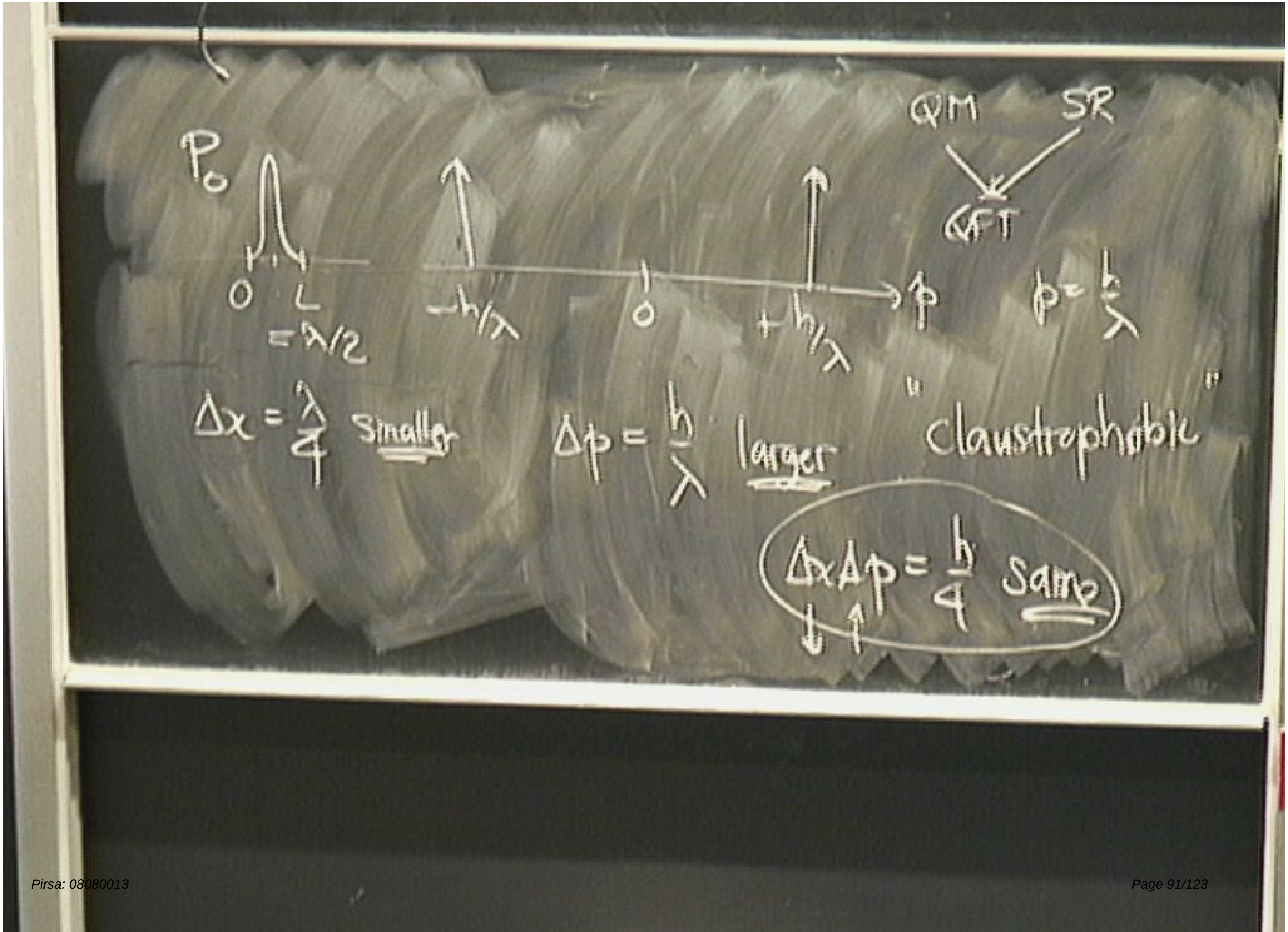
$\uparrow$ $\Delta x = 0$ $\qquad$ $\uparrow$ $\Delta p = 0$

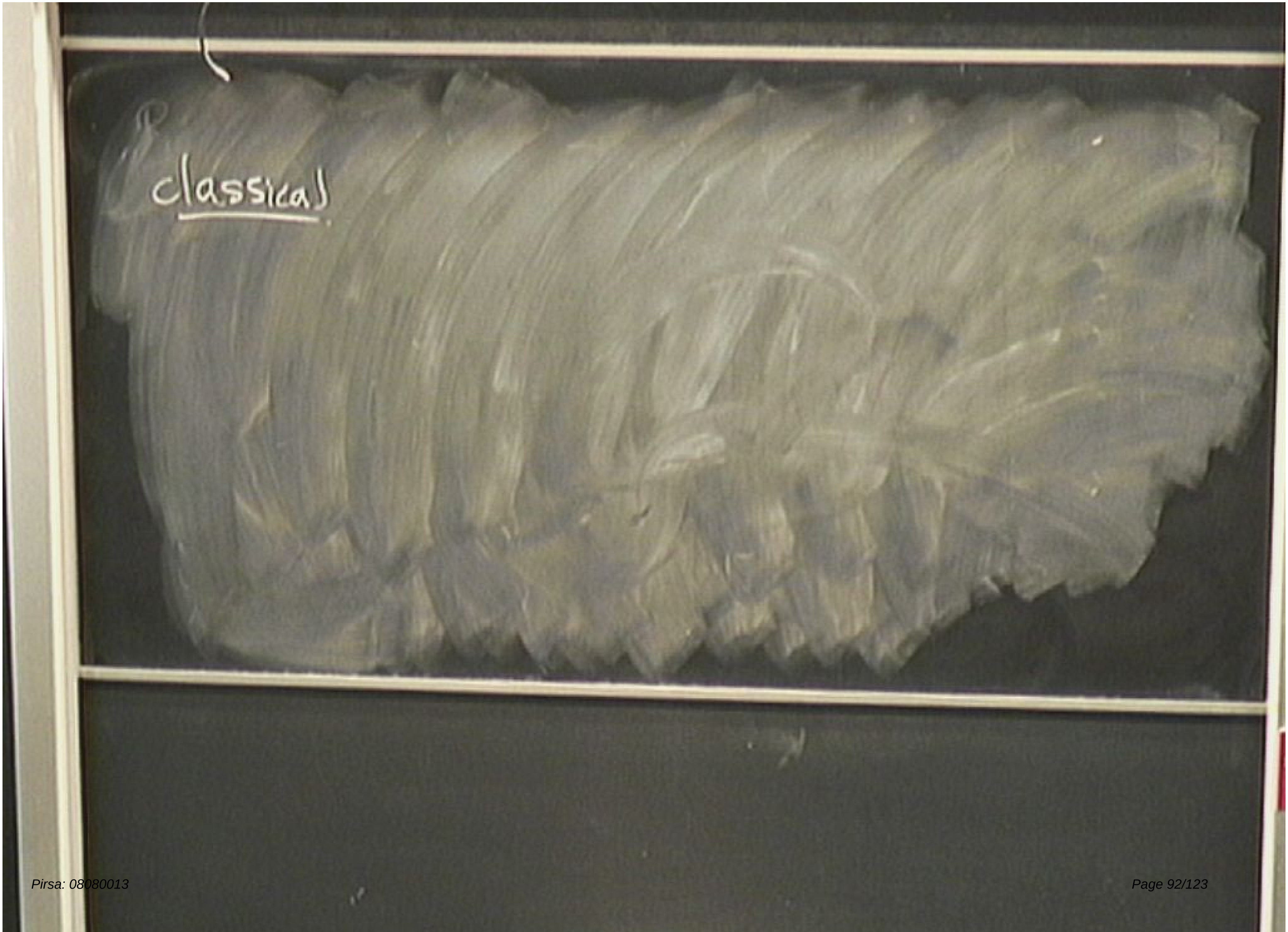
$$E = \frac{p^2}{2m} \quad p = mv$$

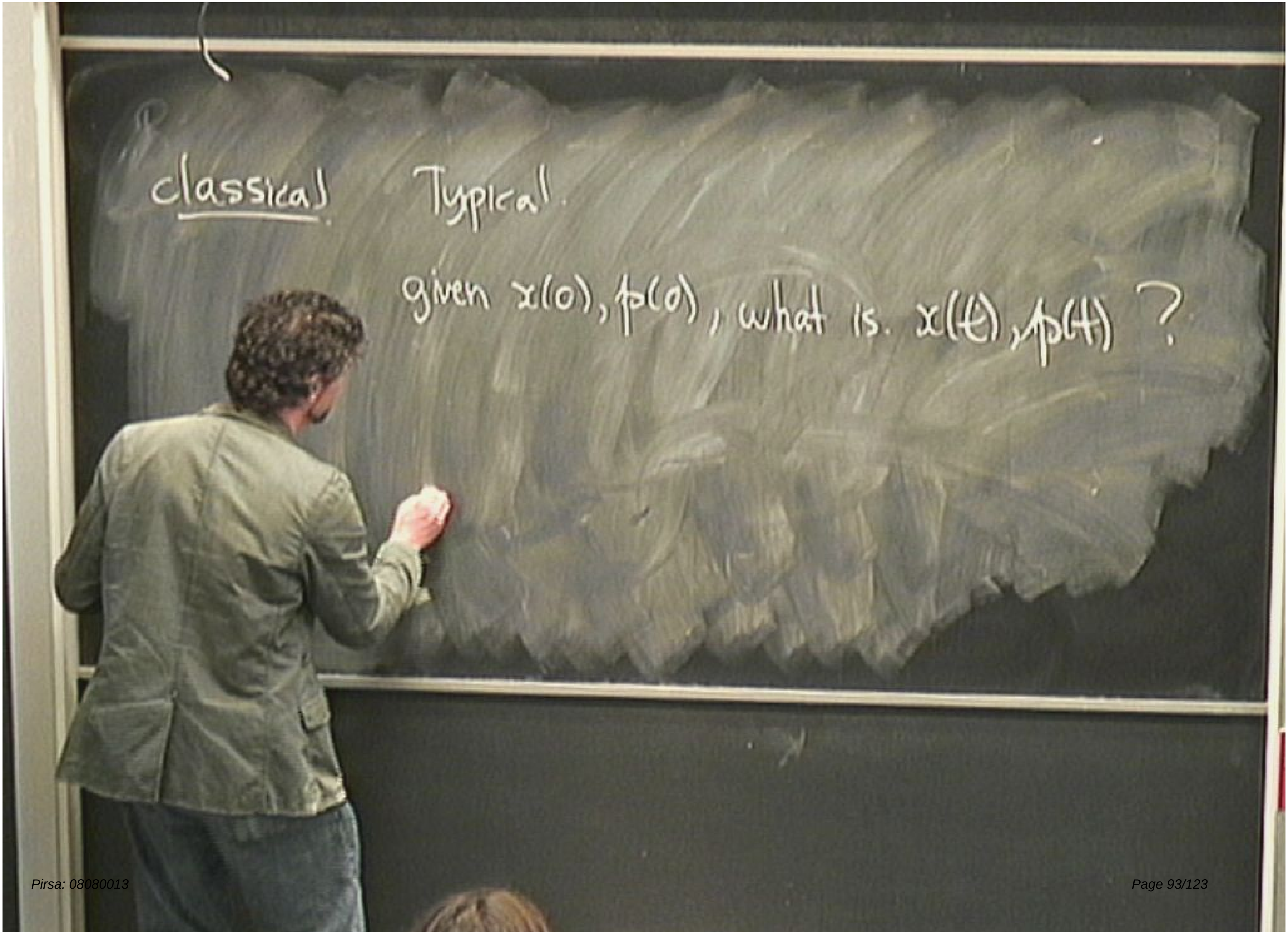
$$E^2 = m^2c^4 + p^2c^2 \rightarrow E \approx mc^2 + \frac{p^2}{2m}$$

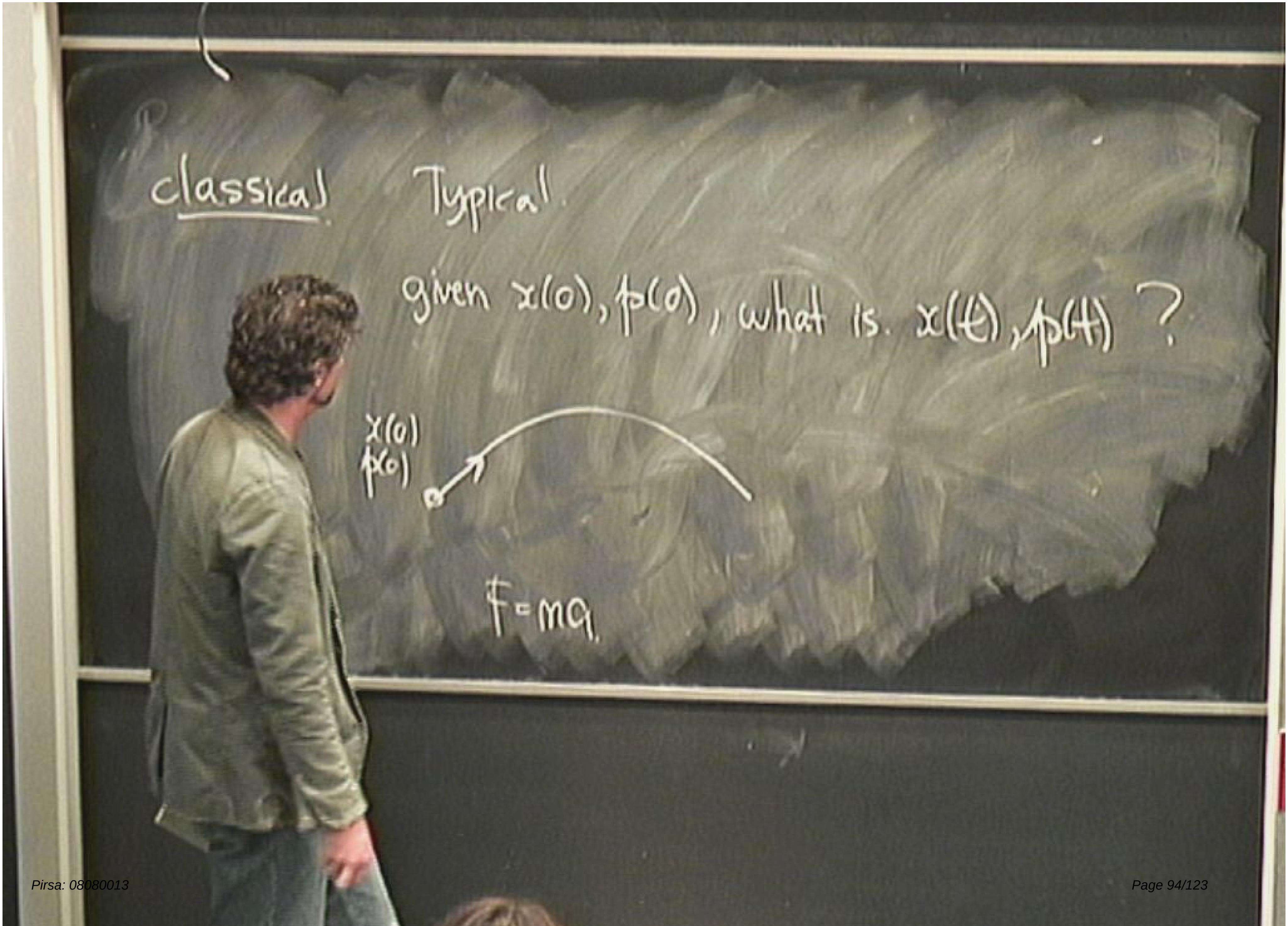


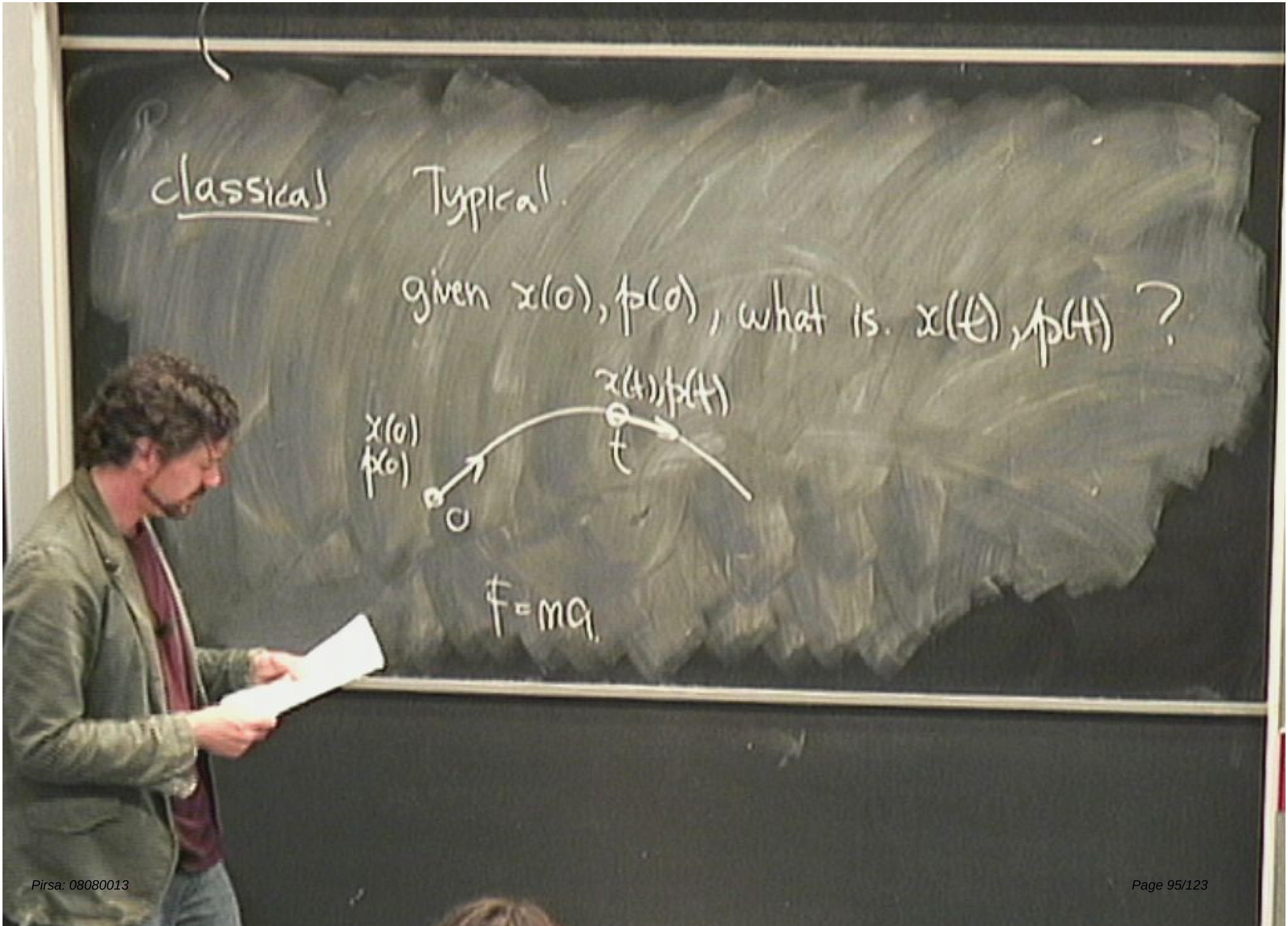
QM
SR
QFT
P_0
0 L
= λ/2
Δx = λ/4 smaller
p = h/λ
same

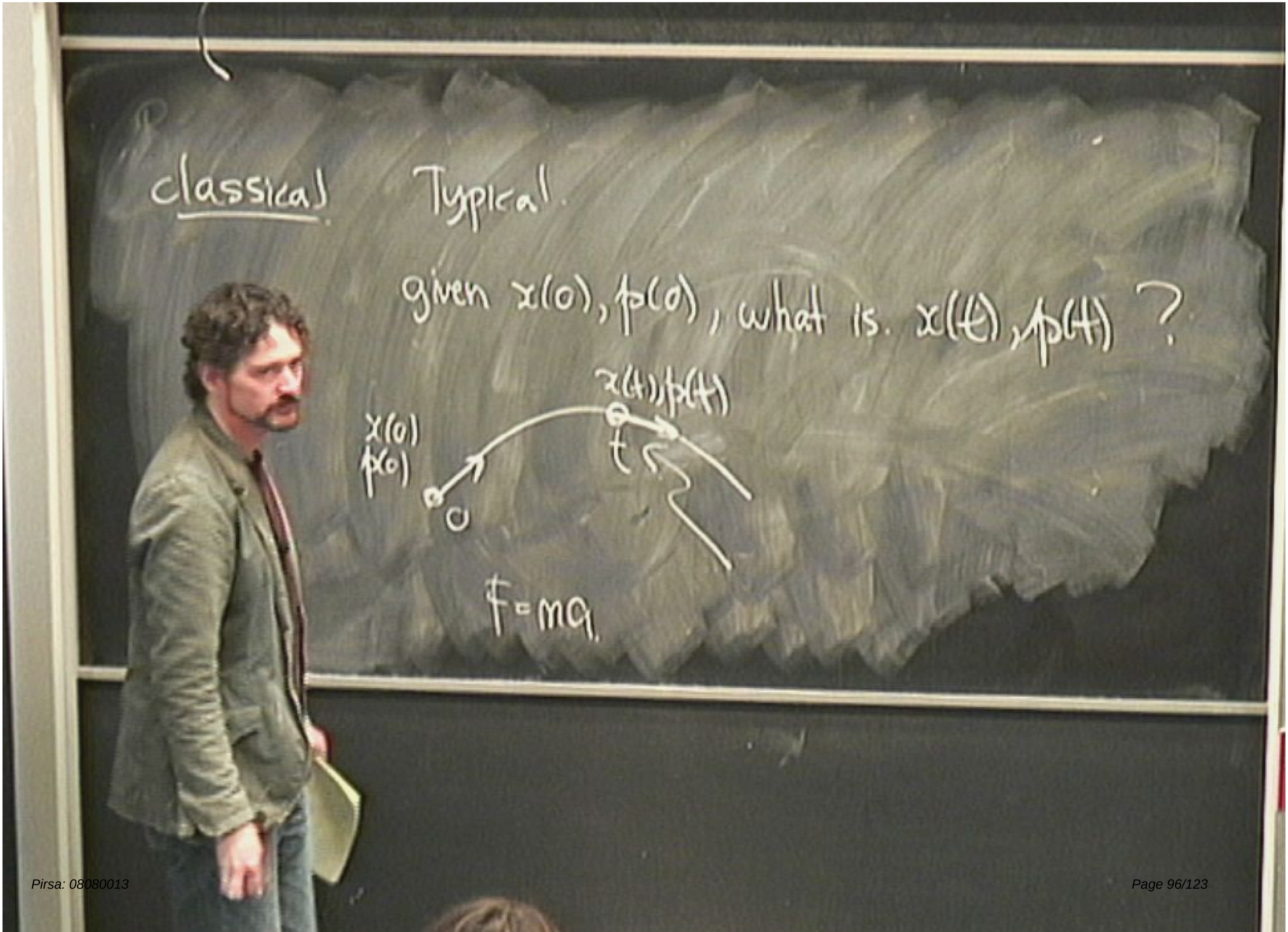

QM
SR
QFT
P0
0
L
=λ/2
−h/T
0
+h/T
p
p = h/λ
Δx = λ/4 smaller
Δp = h/λ larger
"Claustrophobic"
ΔxΔp = h/4 same

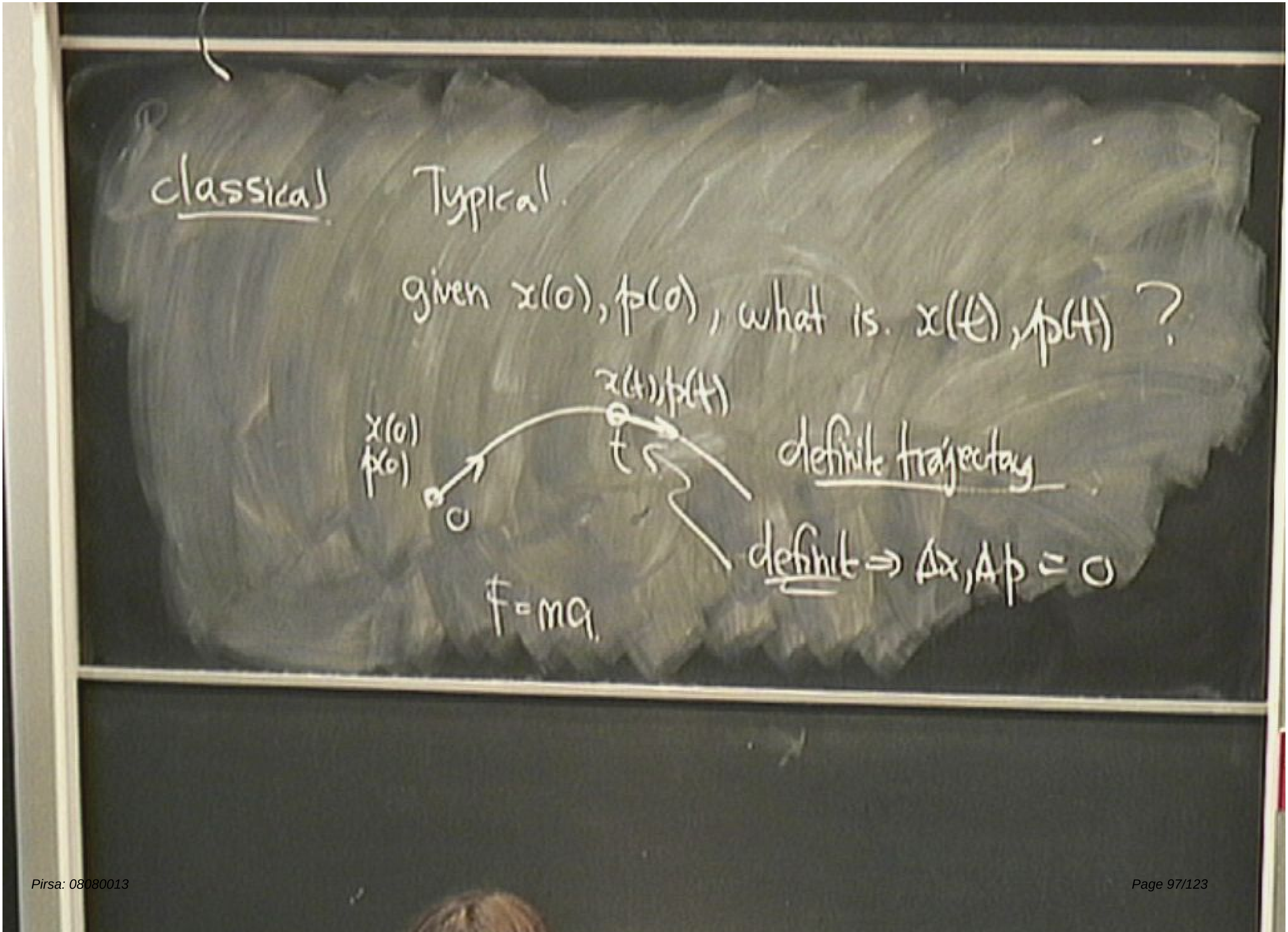

classical

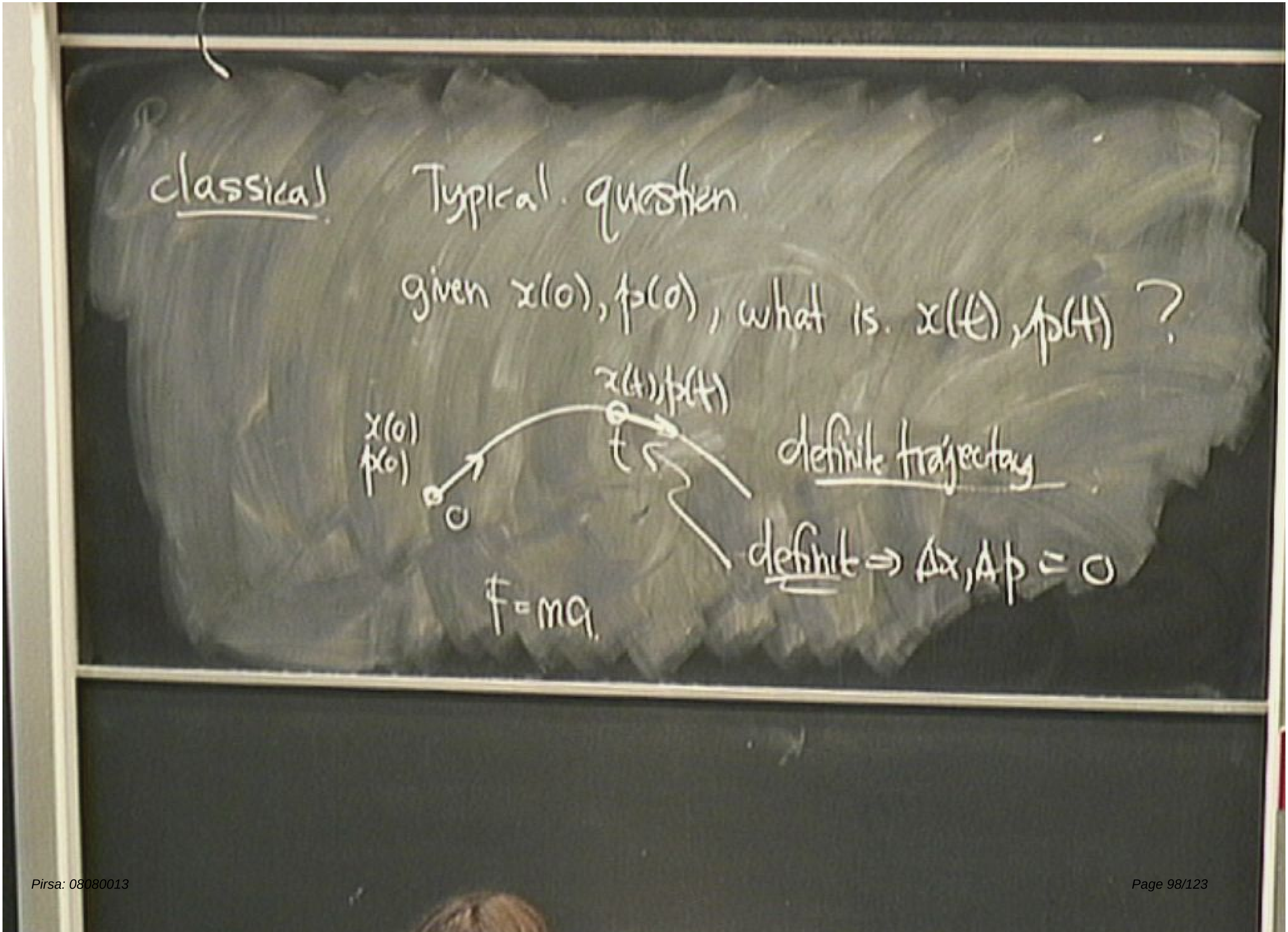

classical
Typical
given $x(0), p(0)$, what is. $x(t), p(t)$?

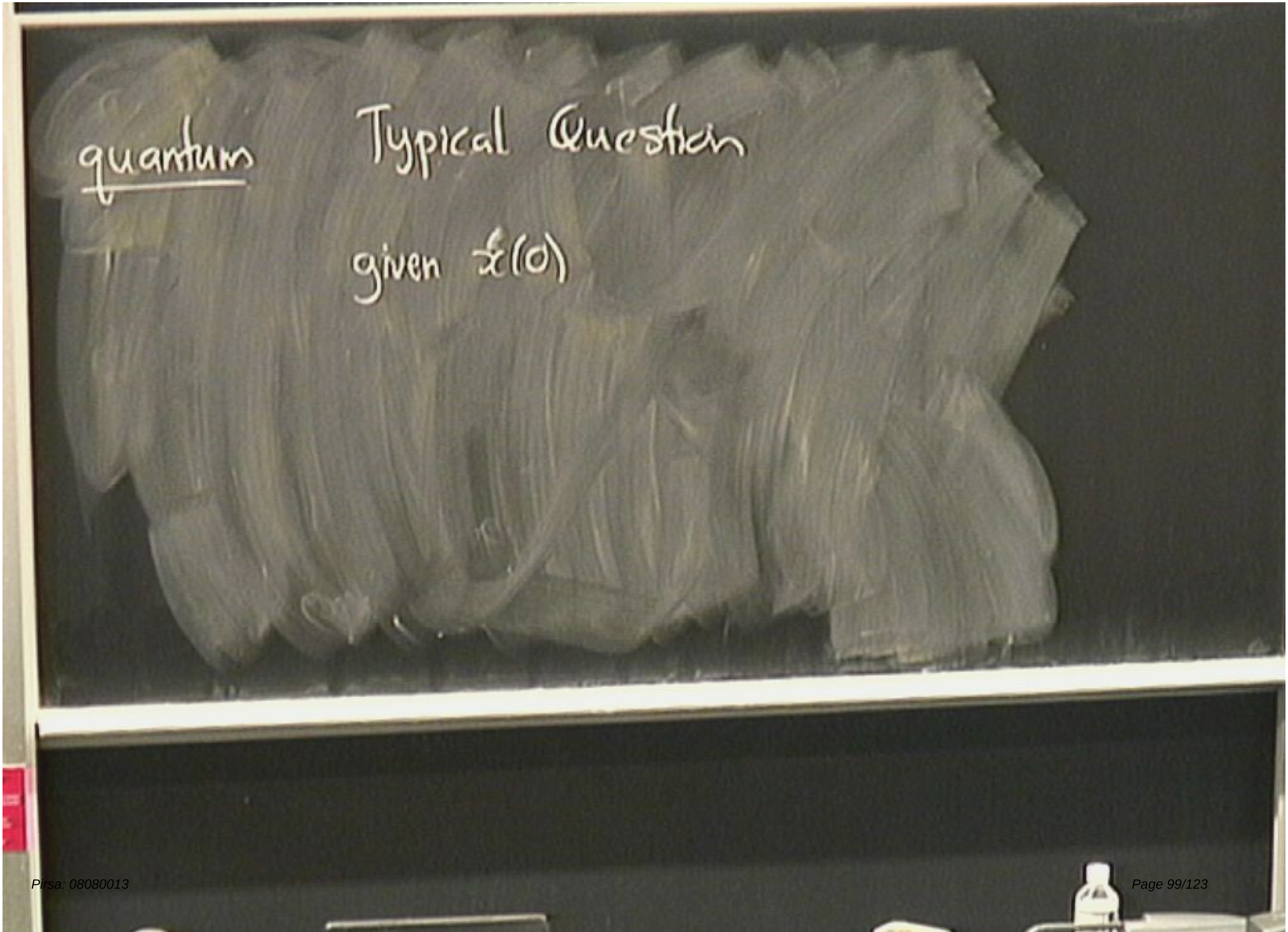

classical
Typical
given x(0), p(0), what is. x(t), p(t) ?
x(0)
p(0)
F=ma

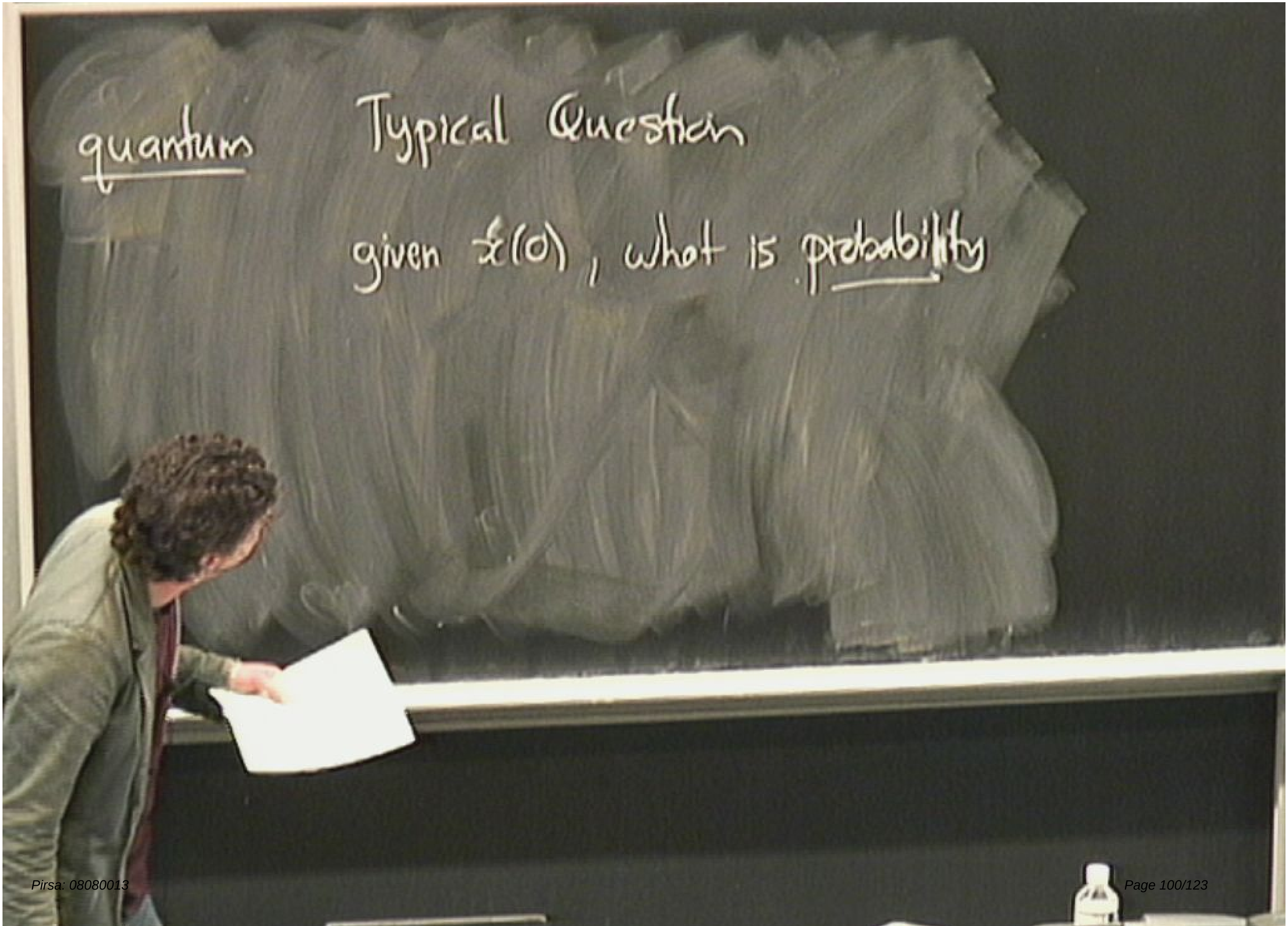

classical
Typical.
given x(0), p(0), what is. x(t), p(t) ?
x(t), p(t)
x(0)
p(0)
0
t
F=ma.

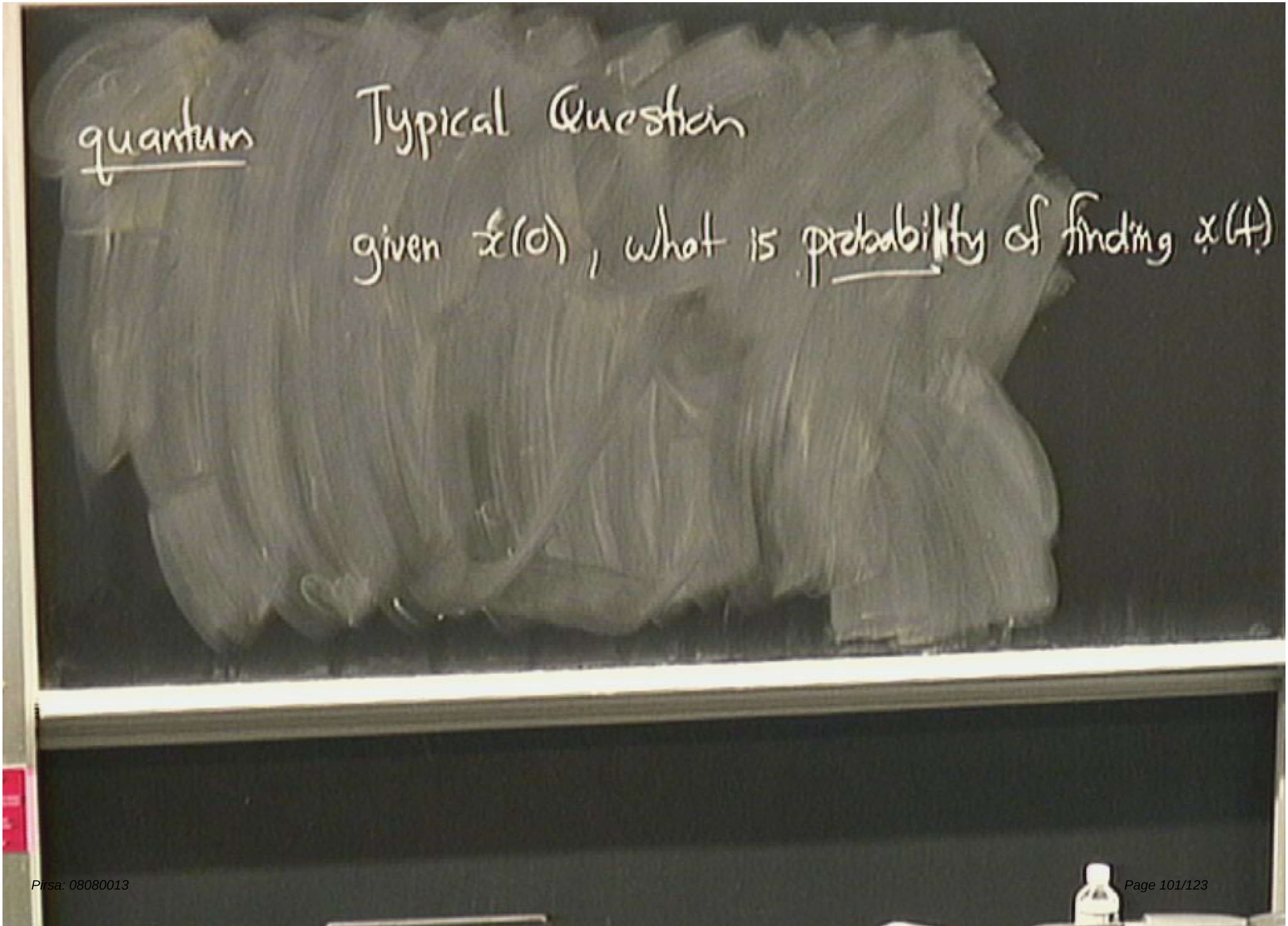

classical
Typical
given x(0), p(0), what is. x(t), p(t) ?
x(t), p(t)
x(0)
p(0)
0
t
F=ma


classical
Typical
given x(0), p(0), what is x(t), p(t) ?
x(t), p(t)
x(0)
p(0)
0
t
definite trajectory
definit ⇒ Δx, Δp = 0
F=ma


classical
Typical question
given x(0), p(0), what is x(t), p(t) ?
x(t), p(t)
x(0)
p(0)
0
t
definite trajectory
definit ⇒ Δx, Δp = 0
F=ma


quantum
Typical Question
given x(0)


quantum
Typical Question
given x(0), what is probability


quantum
Typical Question
given x(0), what is probability of finding x(t)

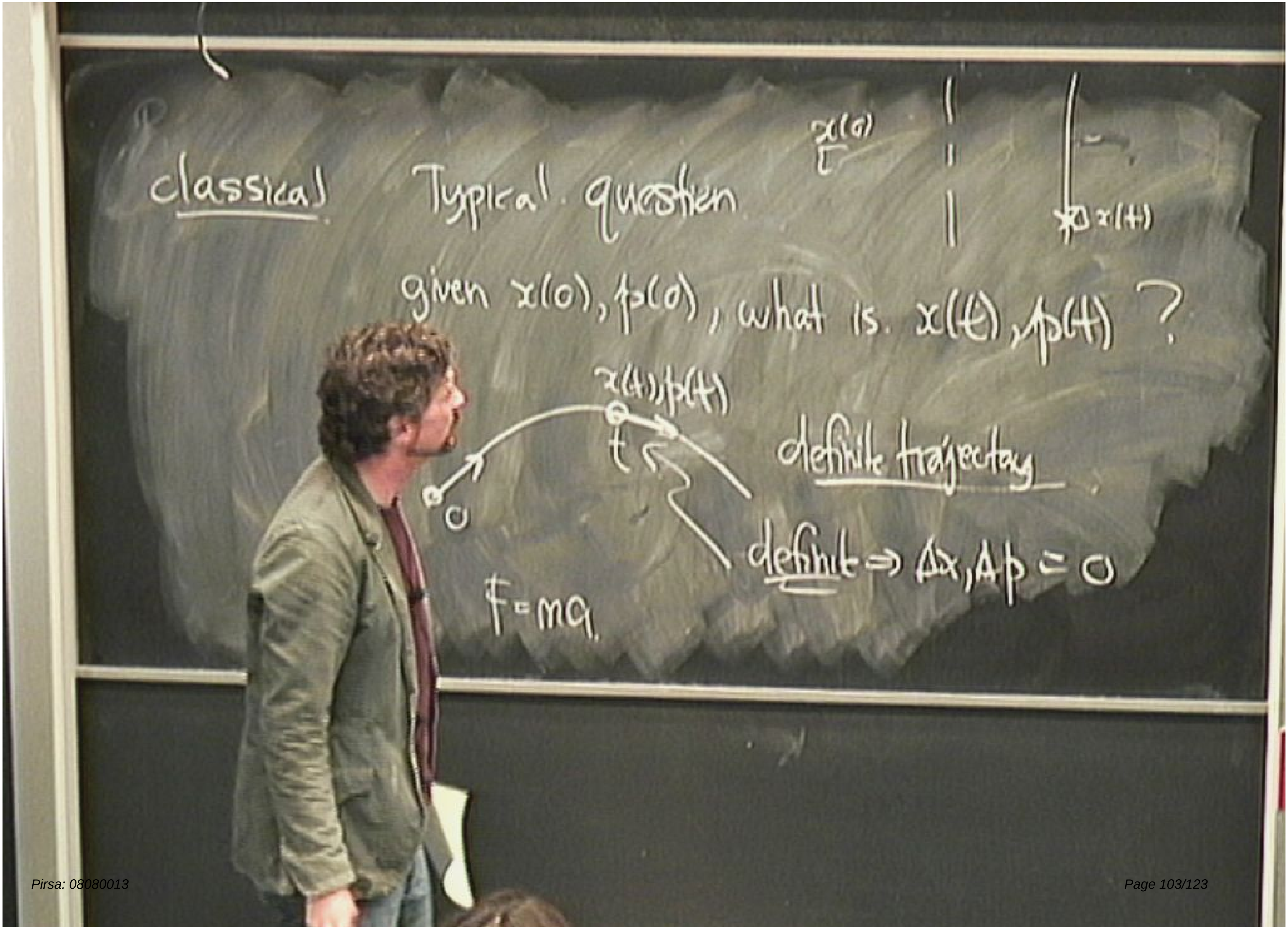
quantum

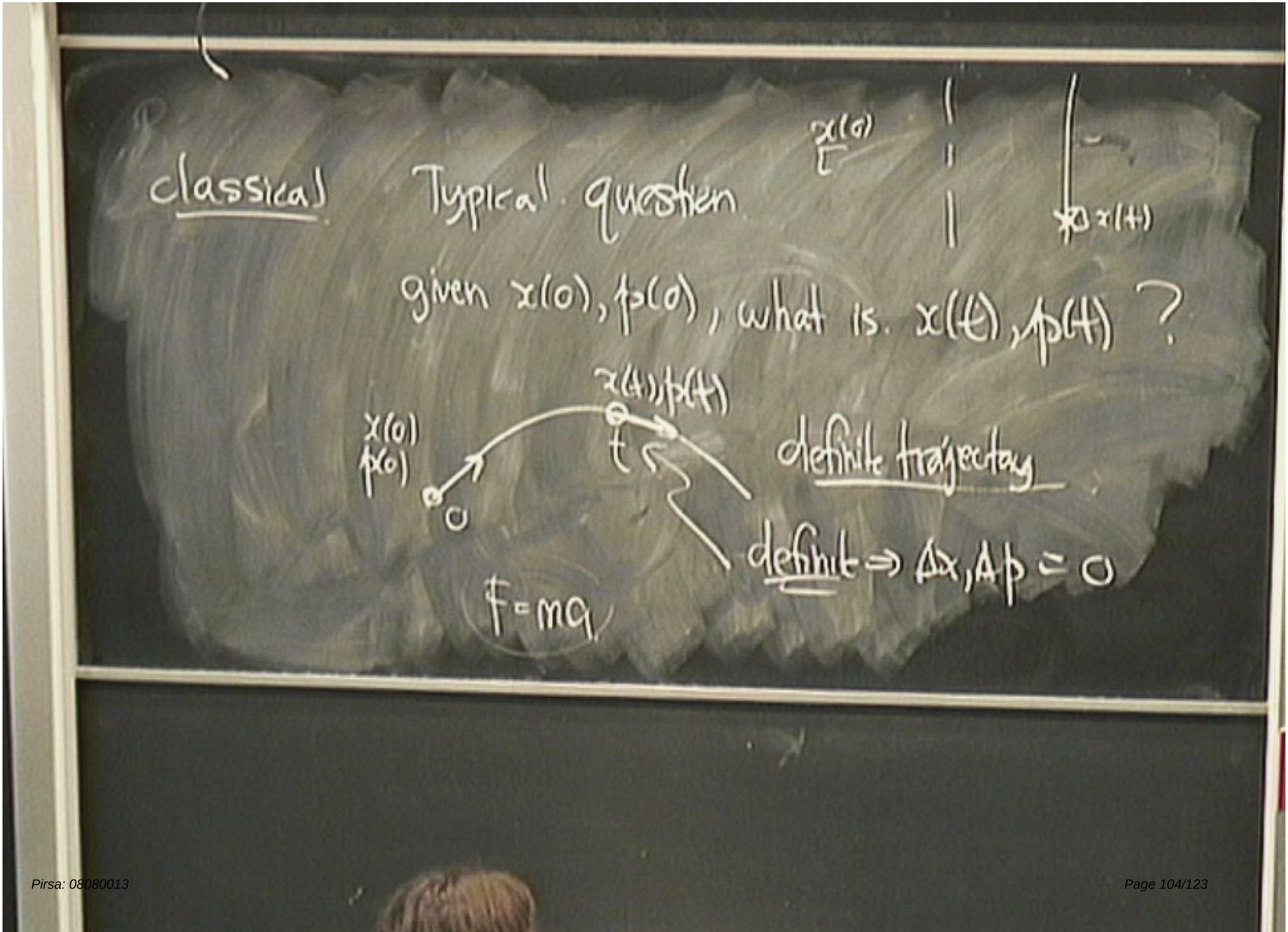
Typical Question

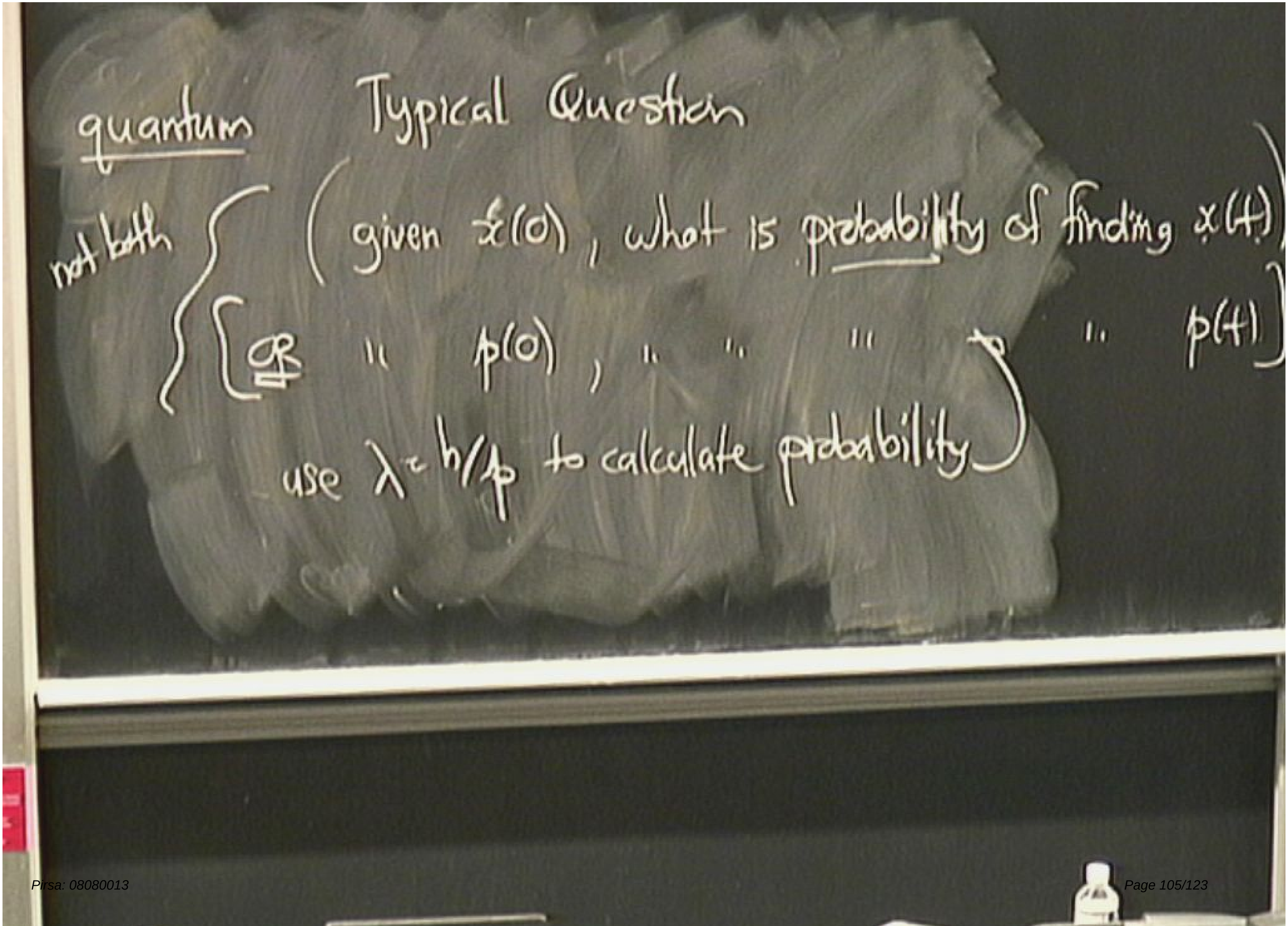
not both:

(given $x(0)$, what is probability of finding $x(t)$)

[OR " $p(0)$, " " " " " $p(t)$]


classical
Typical question
given x(0), p(0), what is x(t), p(t) ?
x(t), p(t)
definite trajectory
definite ⇒ Δx, Δp = 0
F=ma


classical
Typical question
given x(0), p(0), what is x(t), p(t) ?
x(t), p(t)
x(0)
p(0)
0
t
definite trajectory
definit ⇒ Δx, Δp = 0
F = ma
x(t)


quantum
Typical Question
not both
(given x(0), what is probability of finding x(t))
[OR " p(0), " " " " p(t)]
use λ = h/p to calculate probability

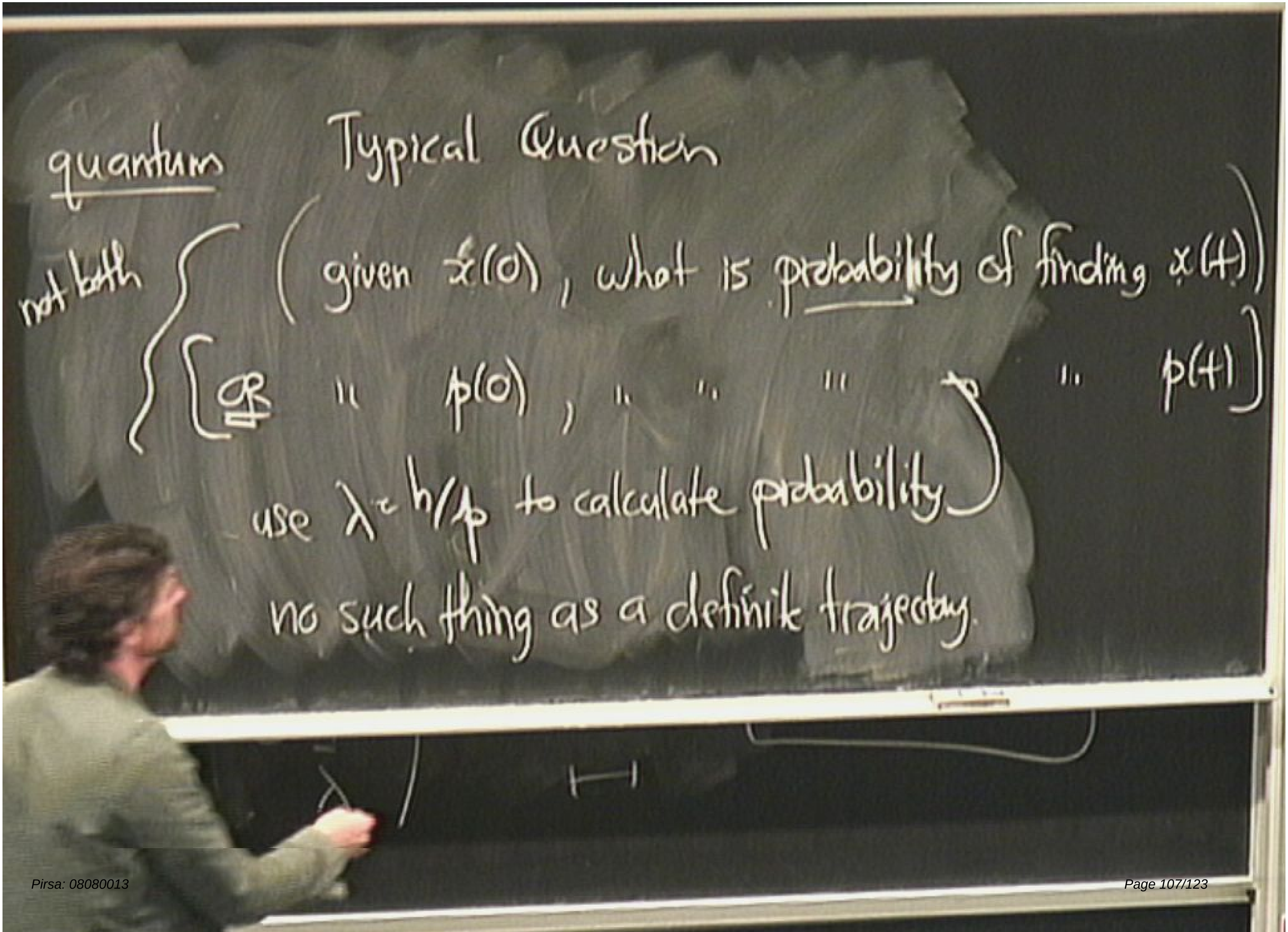
quantum Typical Question

not both
(given $x(0)$, what is probability of finding $x(t)$)
[OR " $p(0)$, " " " " $p(t)$]

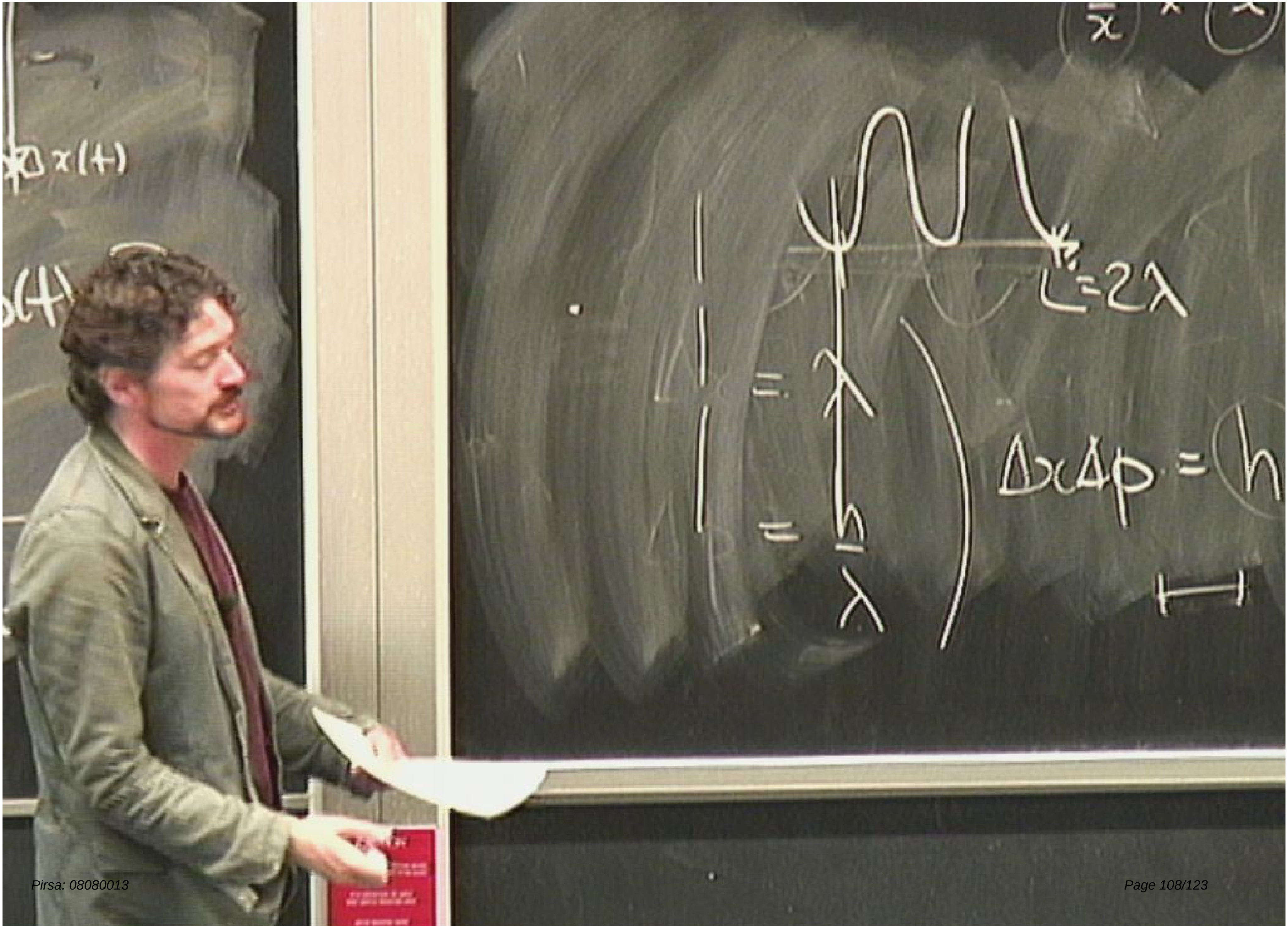
use $\lambda = h/p$ to calculate probability

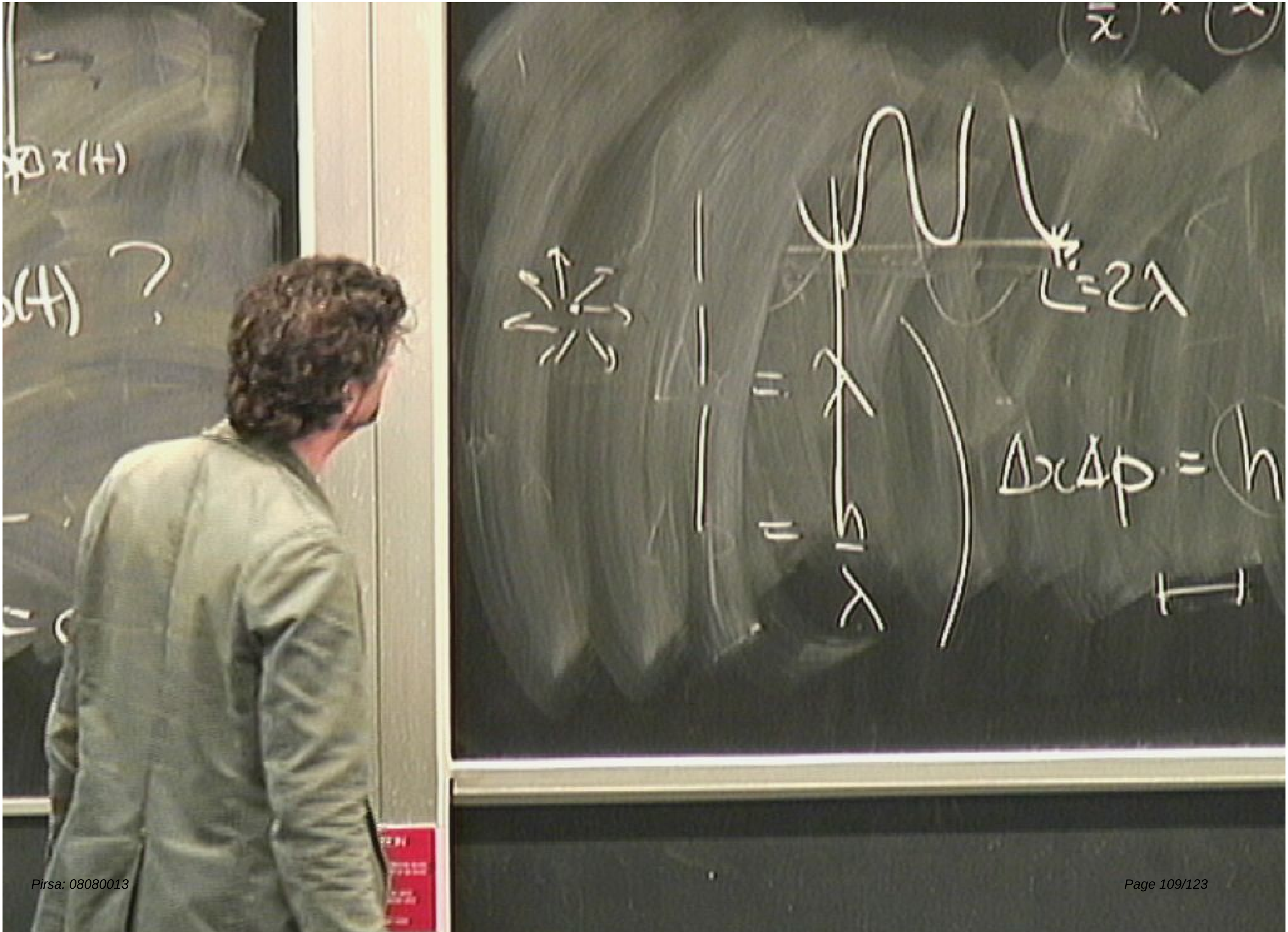
no such thing as a definite trajectory.

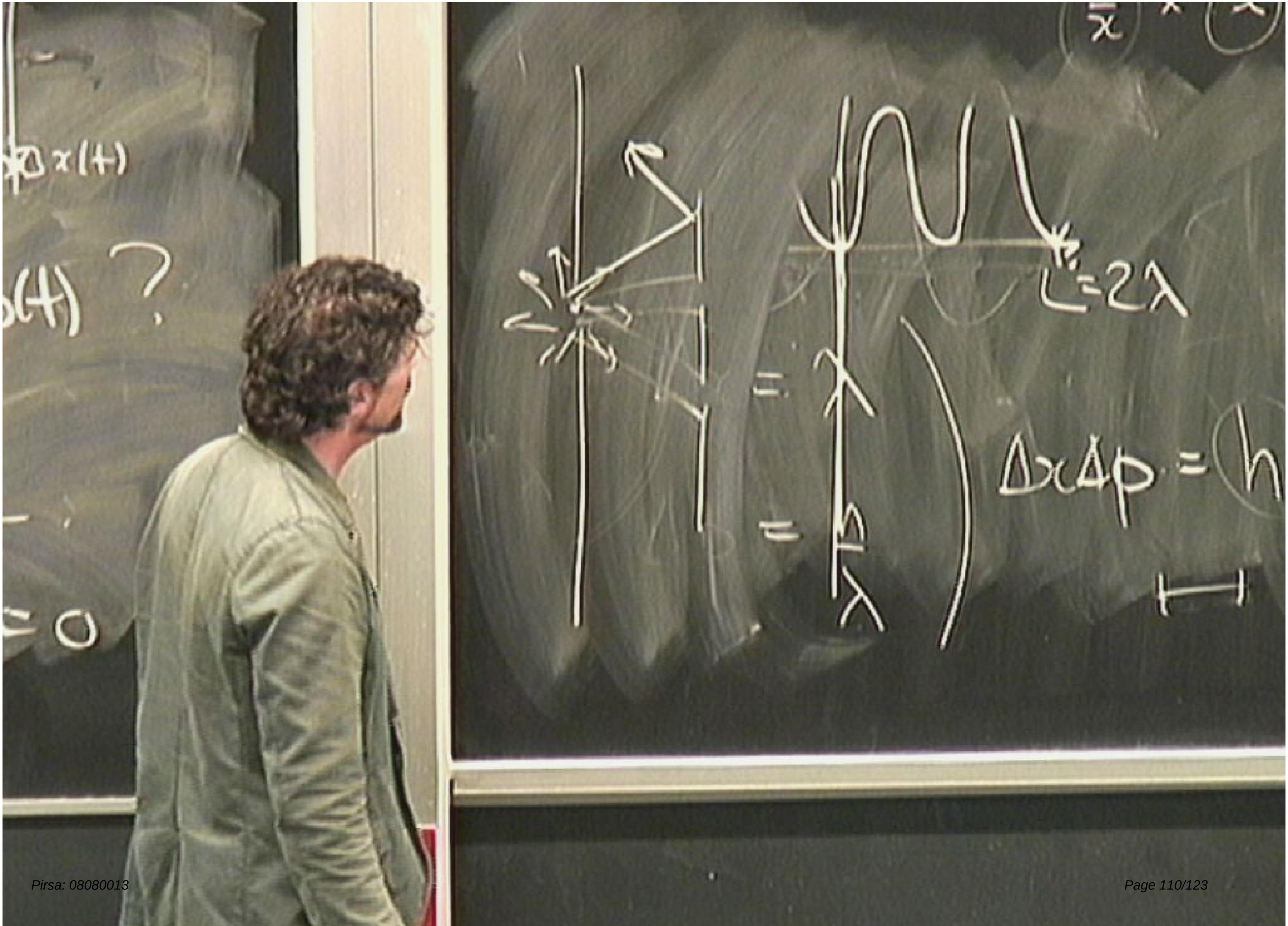
$\frac{c}{x} \times (x) = \$$ general. $\Delta p \geq \frac{h}{4\pi \Delta x}$

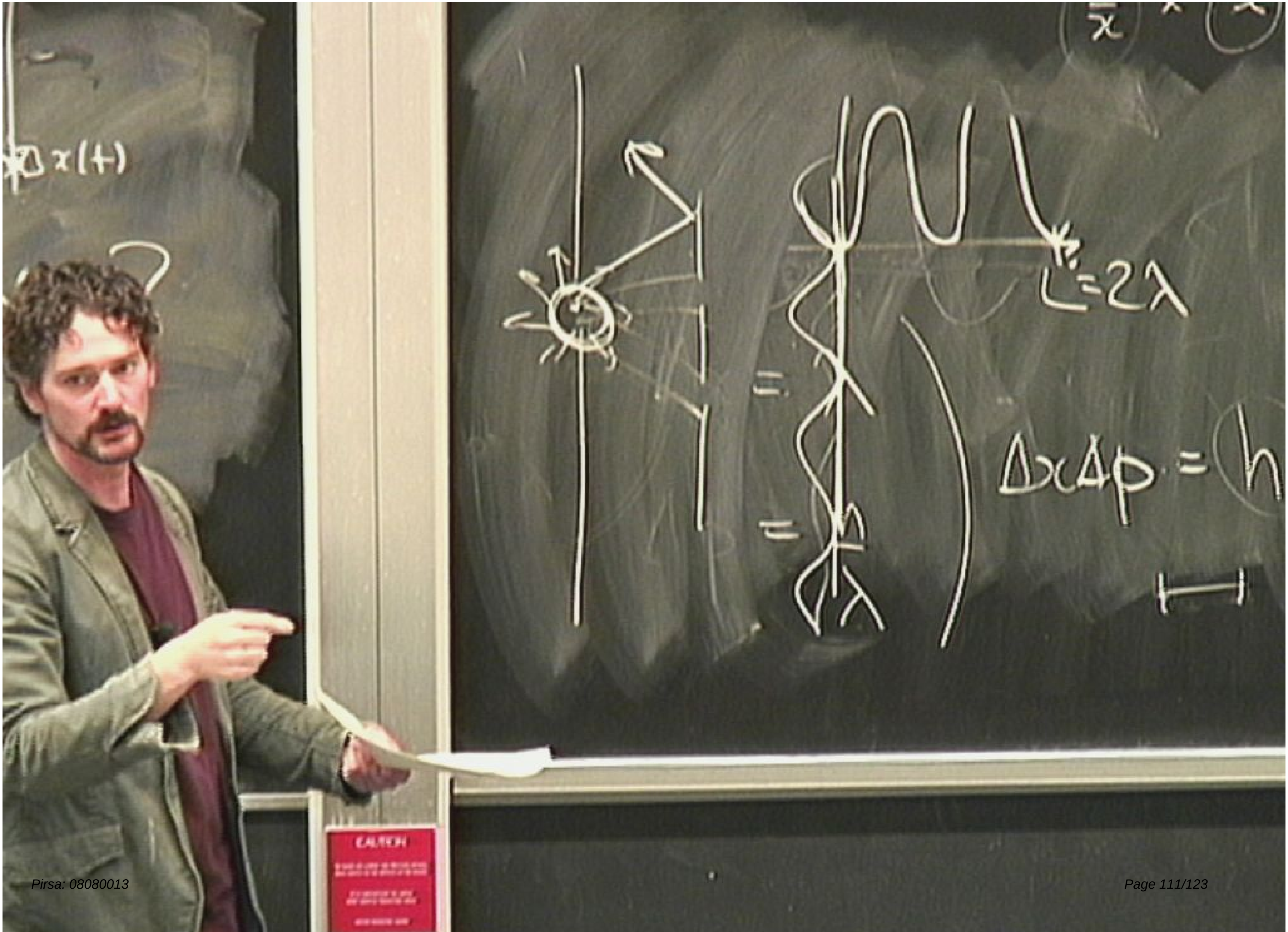


quantum
Typical Question
not both
(given x(0), what is probability of finding x(t))
[OR " p(0), " " " " " p(t)]
use λ = h/p to calculate probability
no such thing as a definite trajectory.

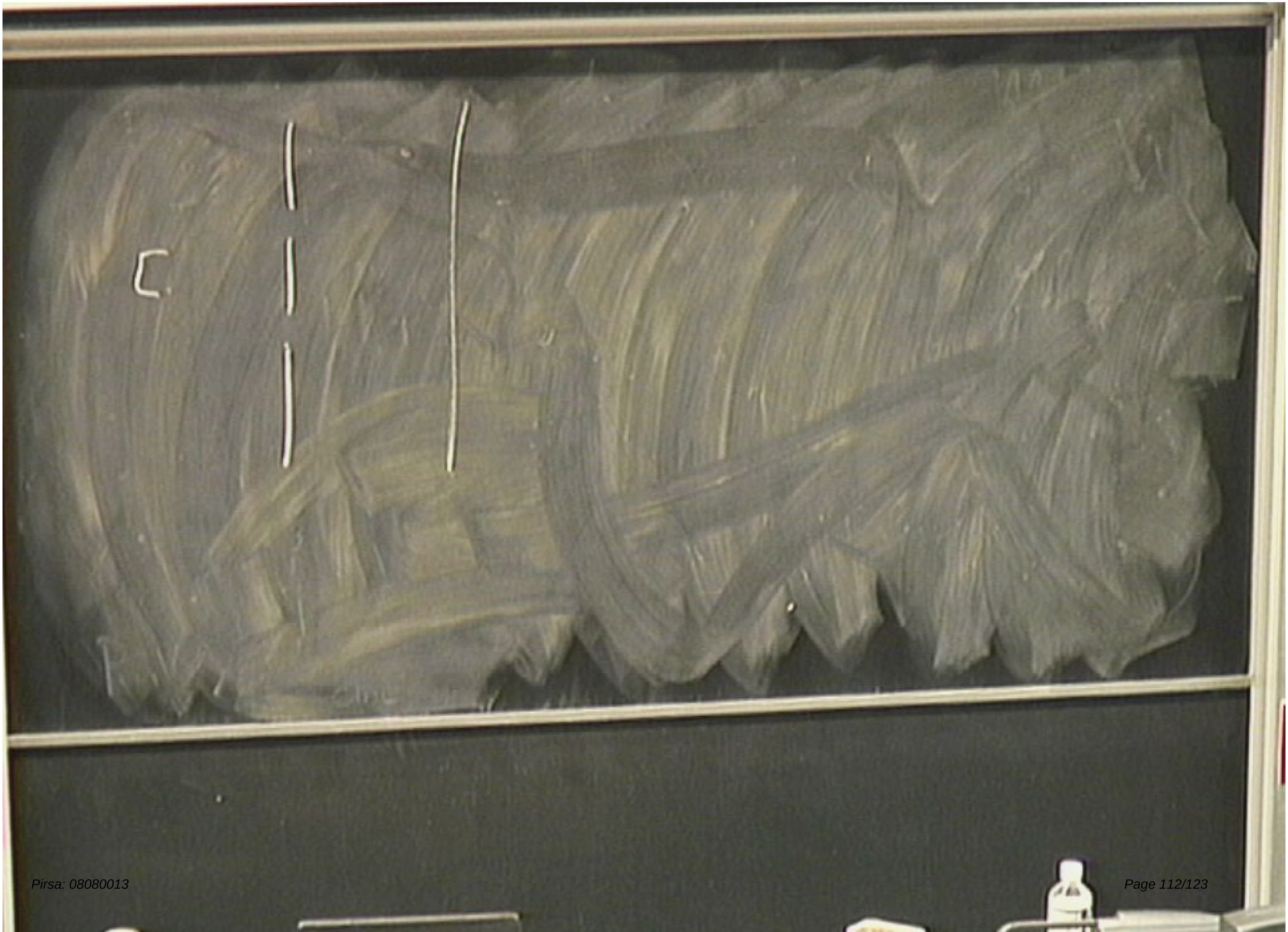

x(t)
L=2λ
ΔxΔp = h

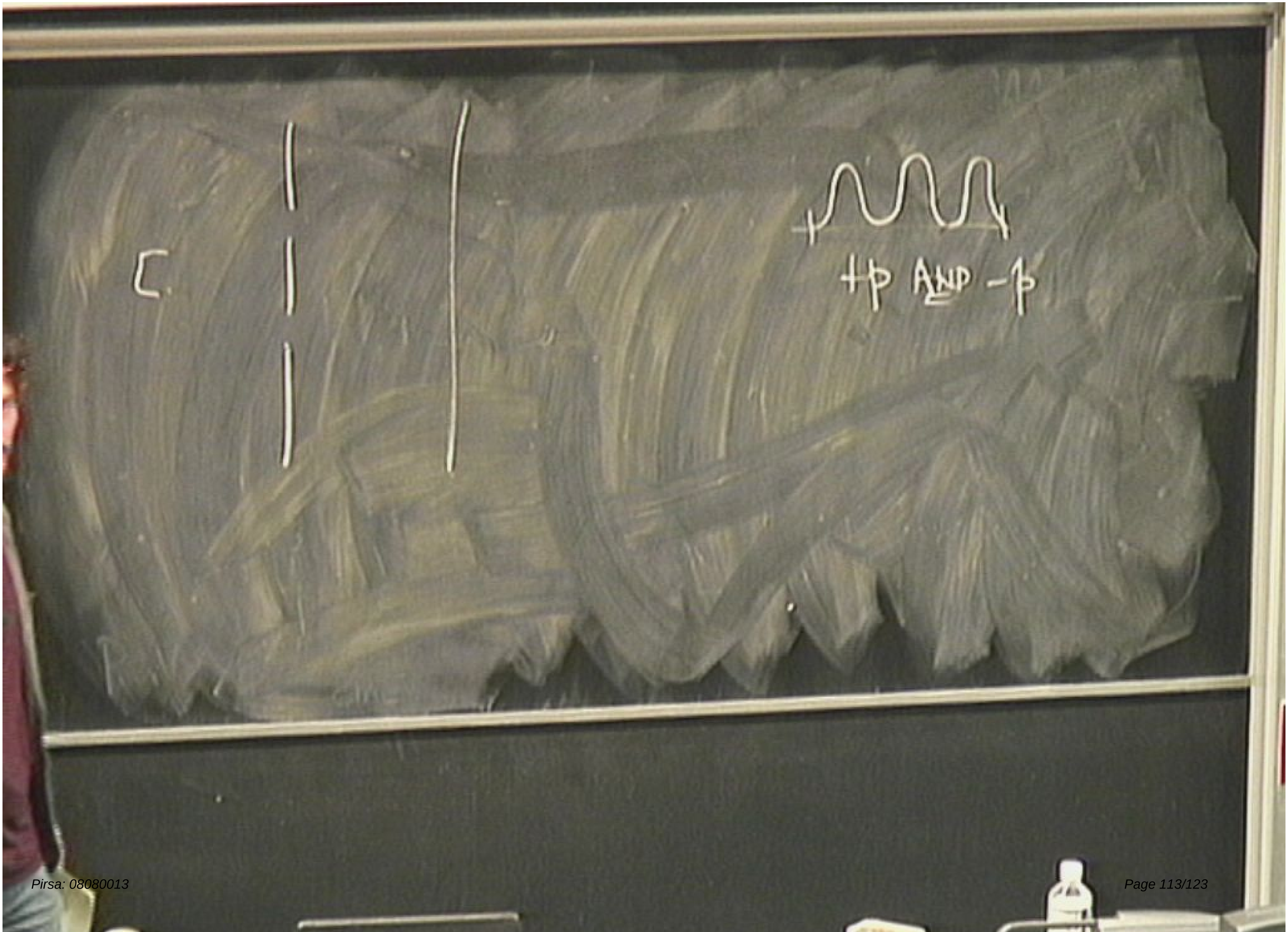

x(t)
L=2λ
= λ
= h/λ
ΔxΔp = h


x(t)
L=2λ
ΔxΔp = h



Δx(t)
L=2λ
ΔxΔp = h
CAUTION

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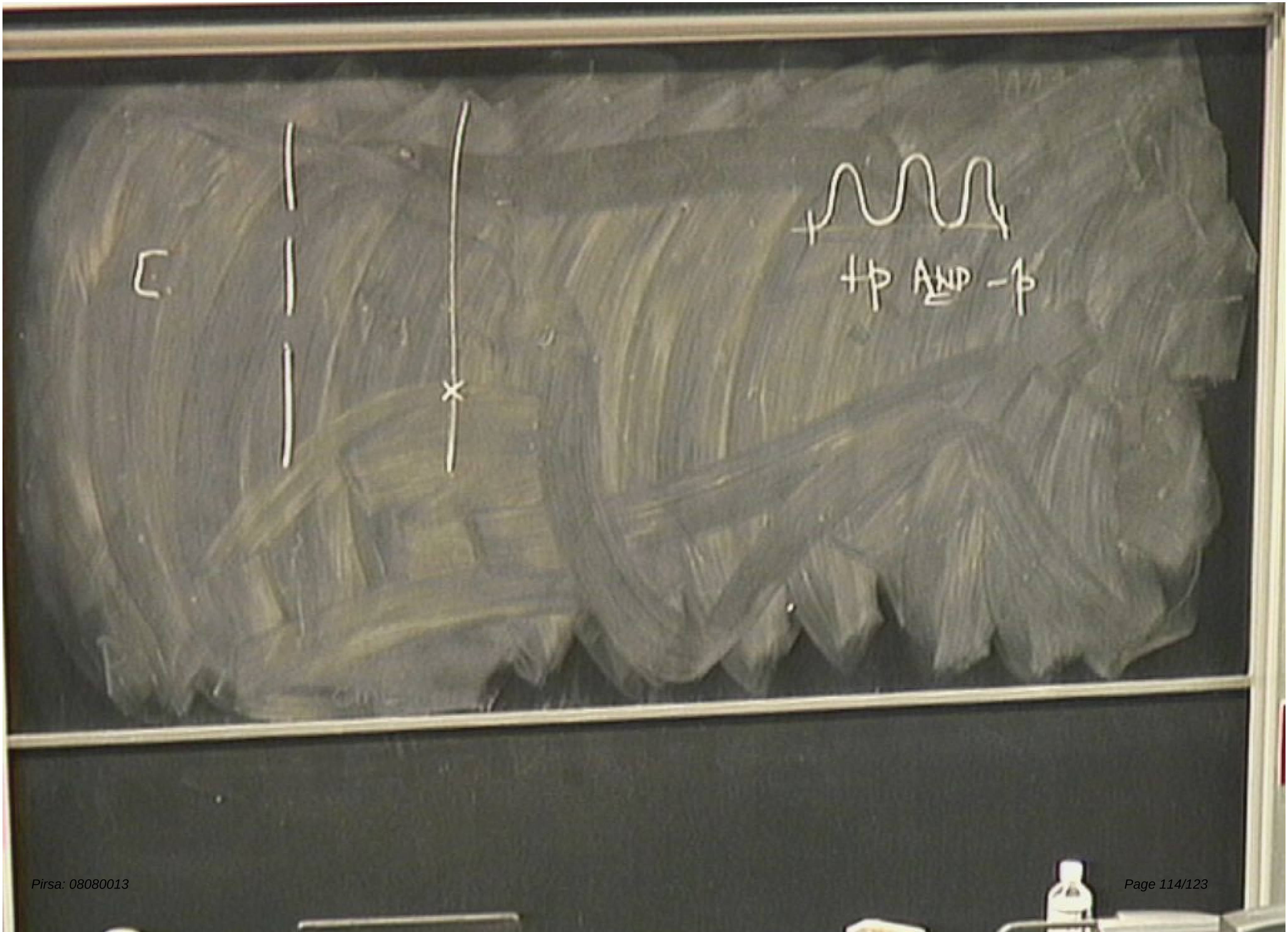
C.
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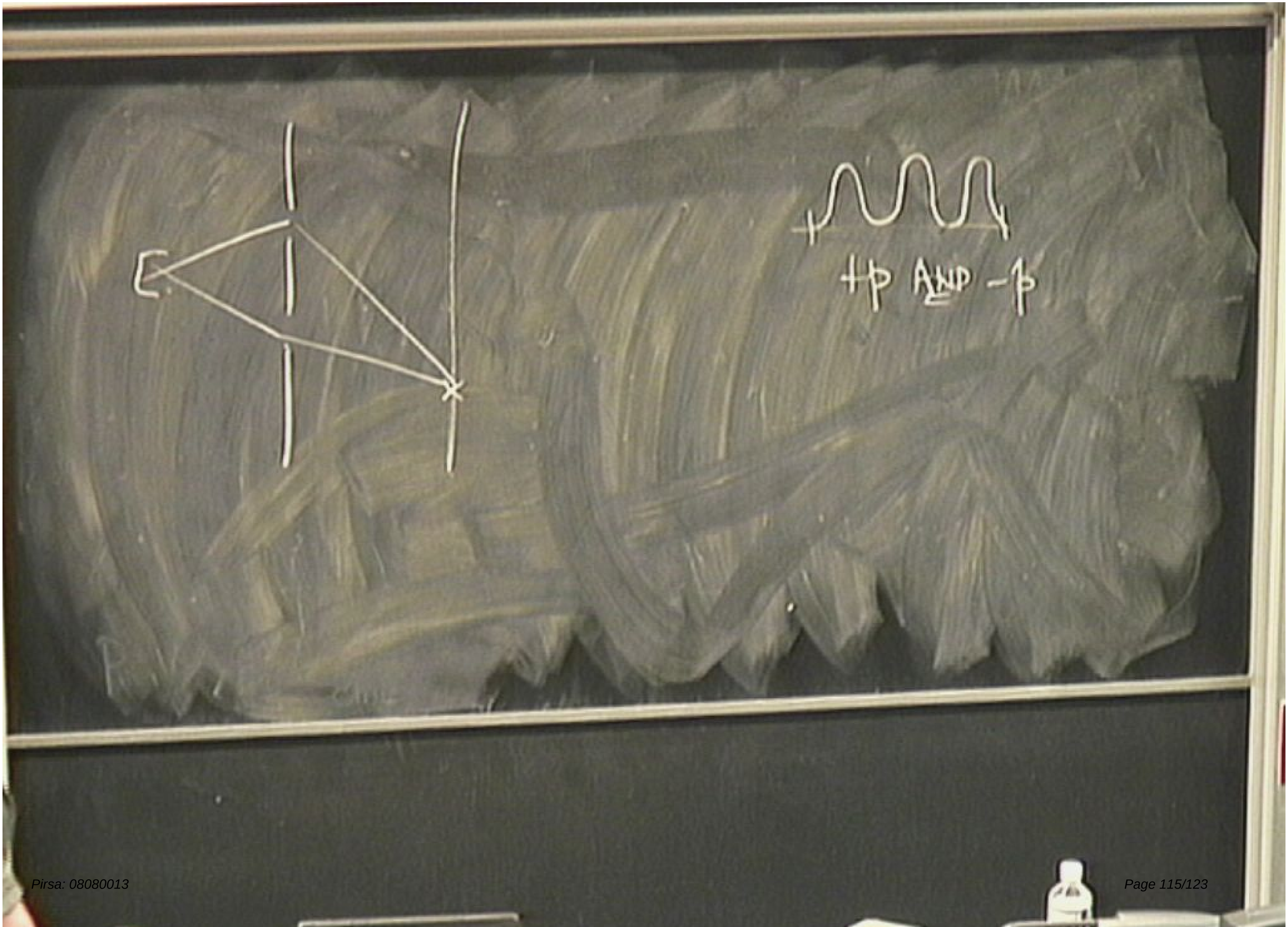
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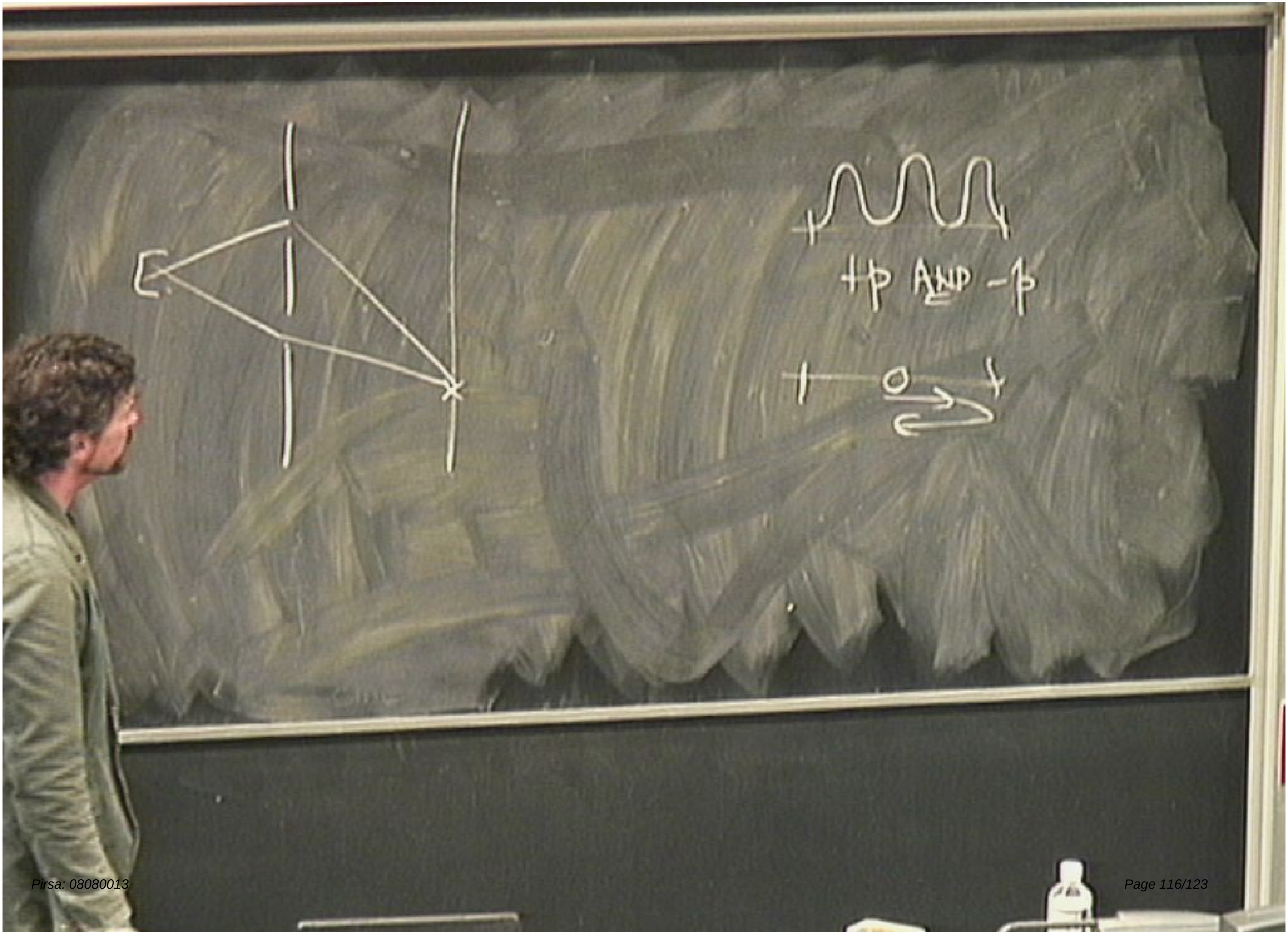
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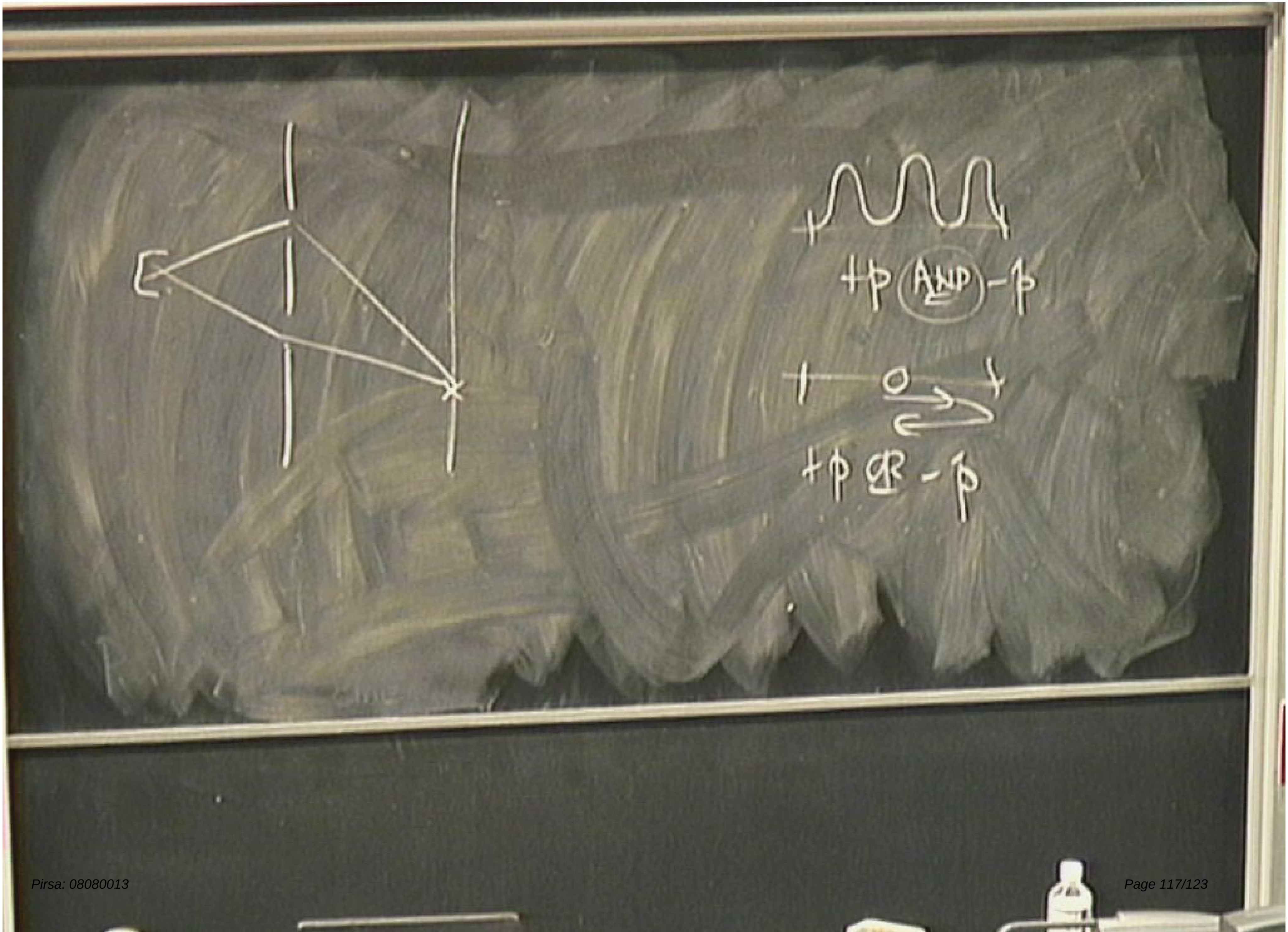
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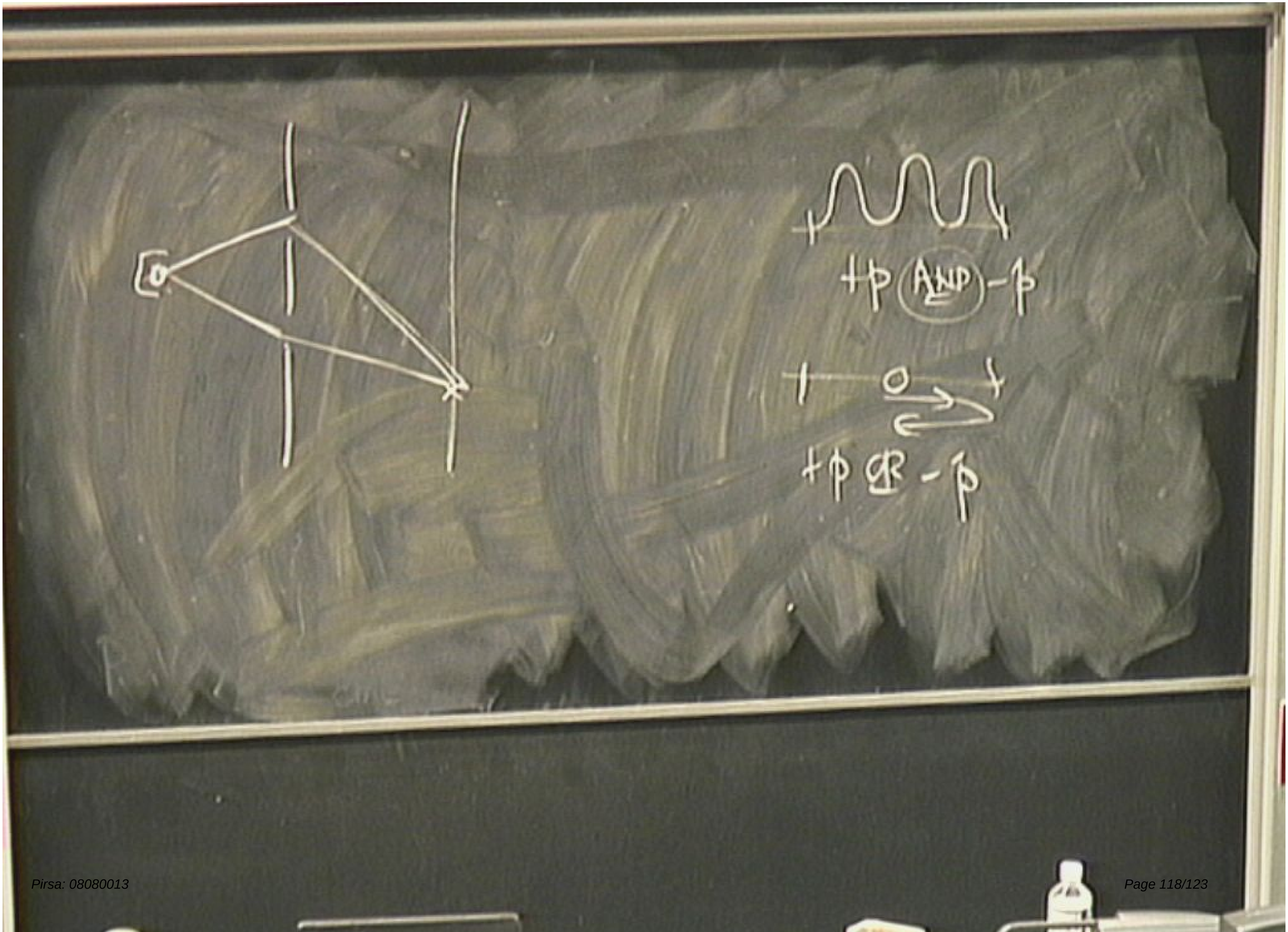
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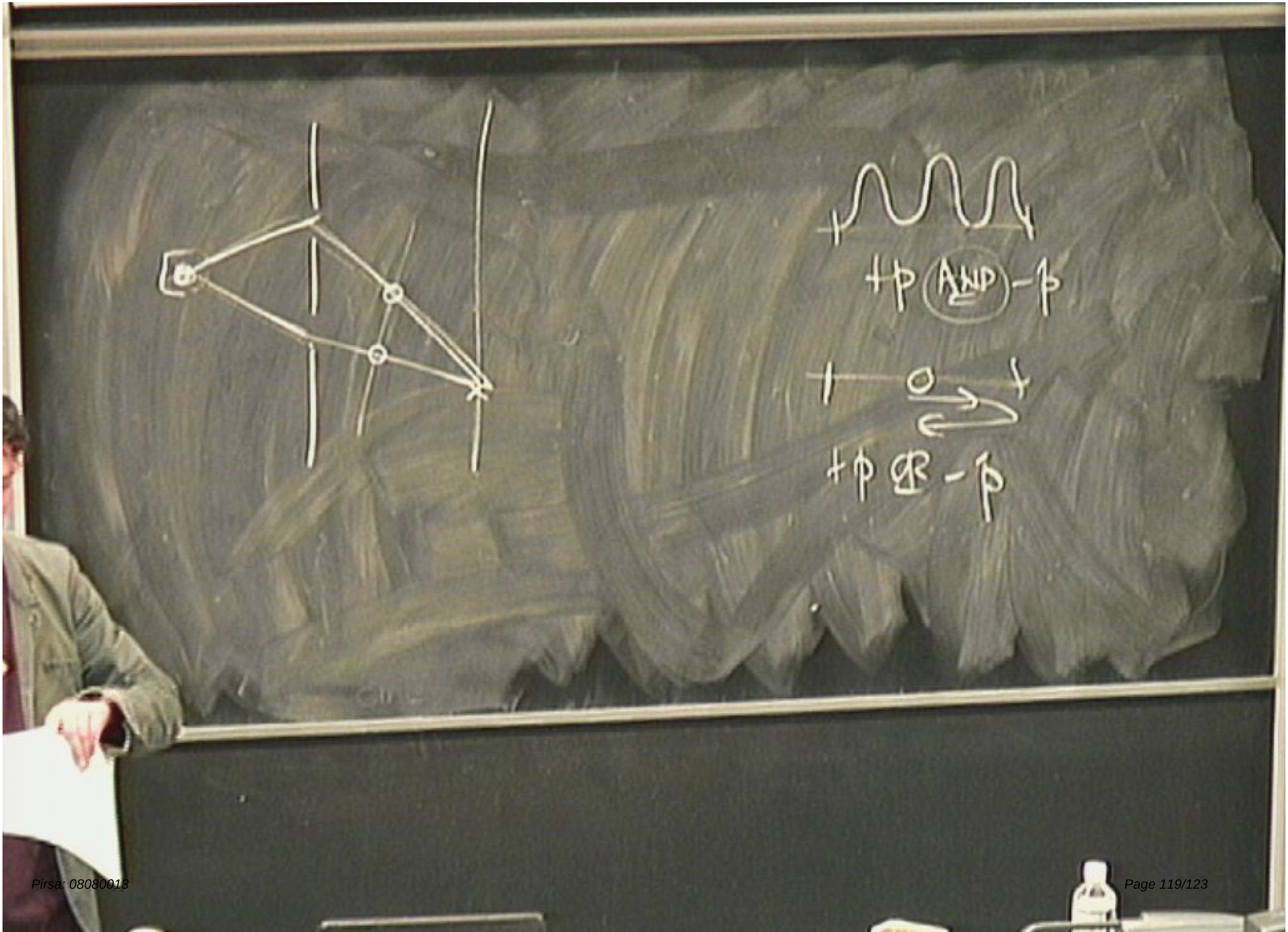
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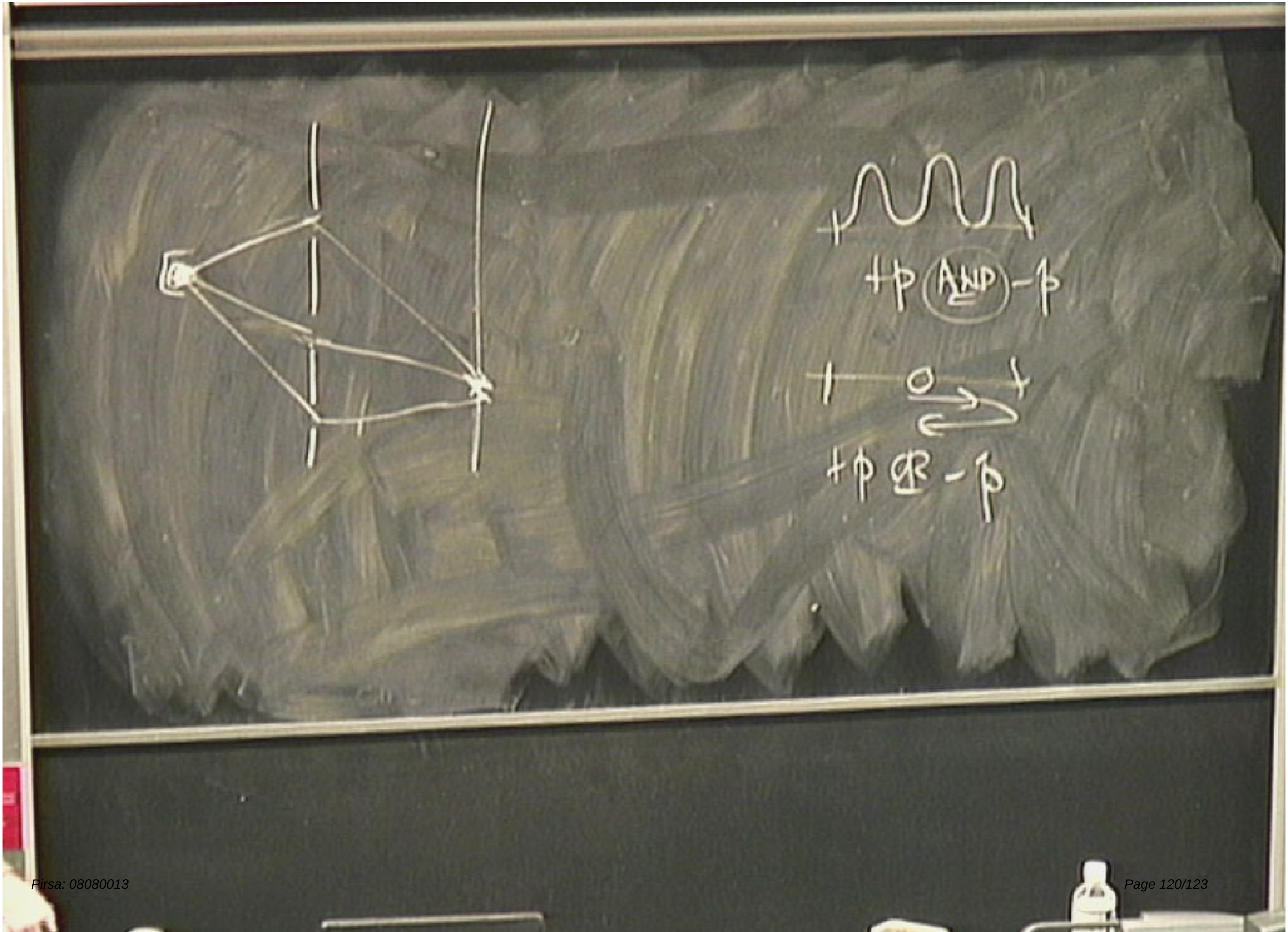
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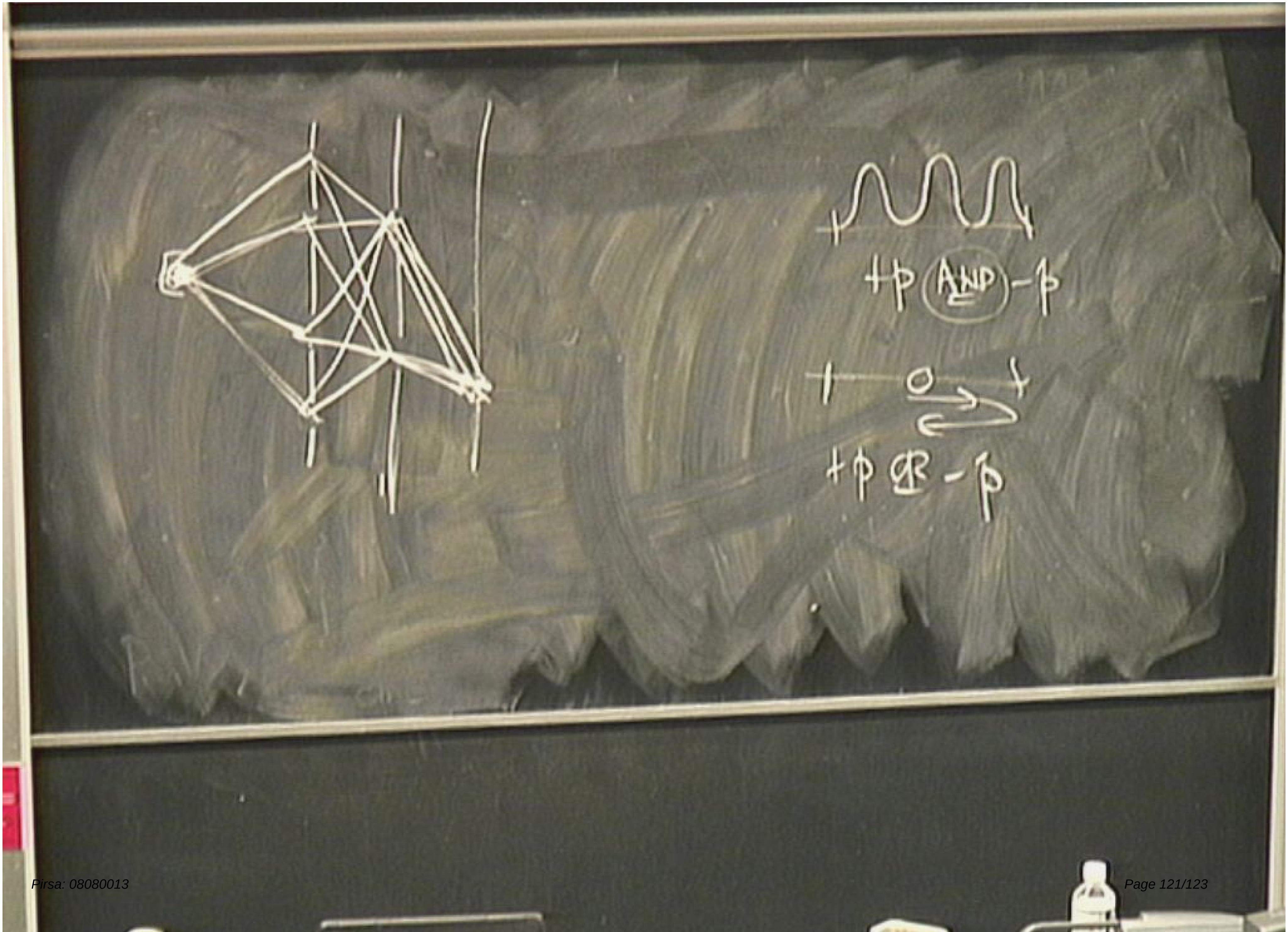
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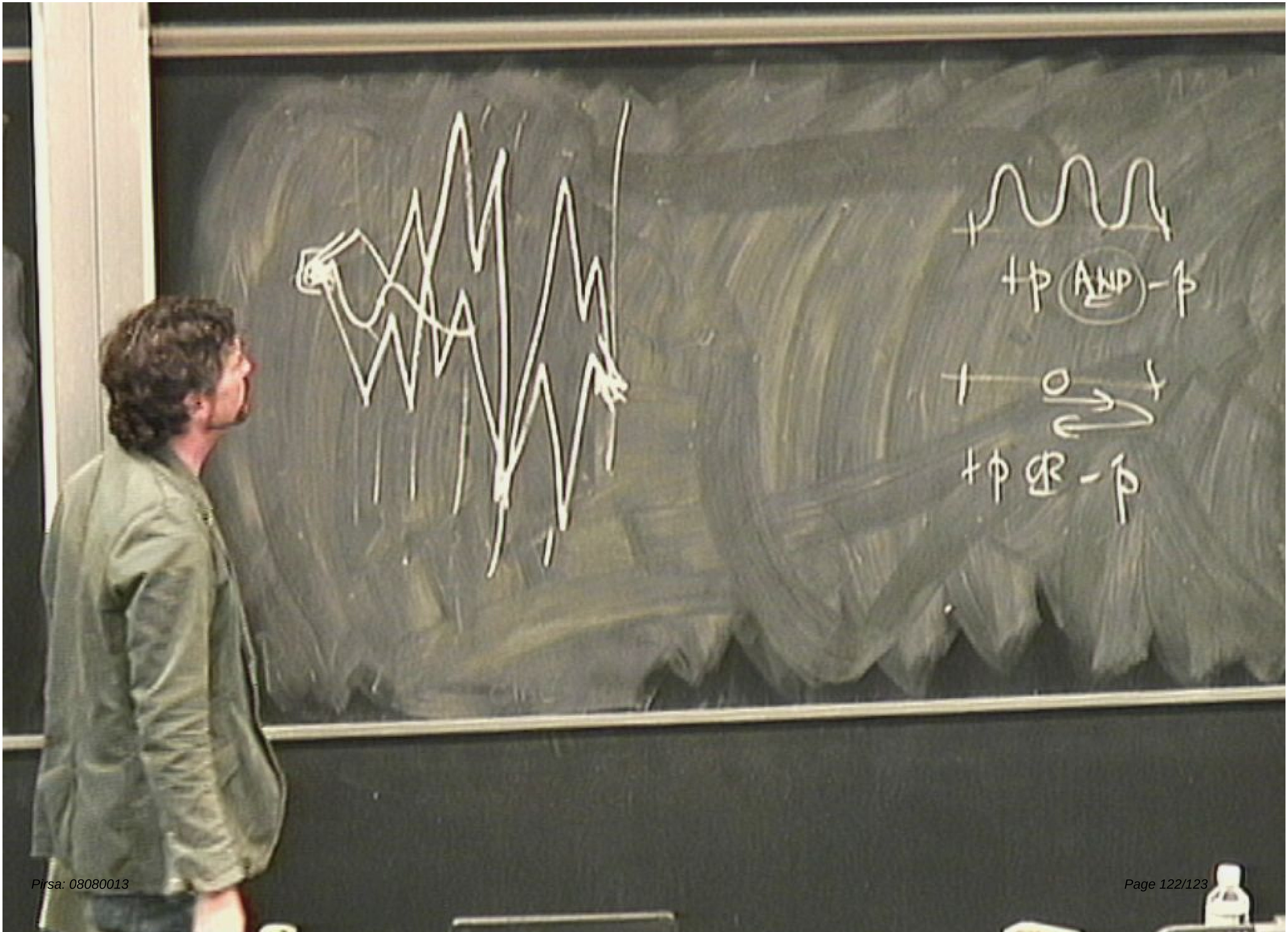
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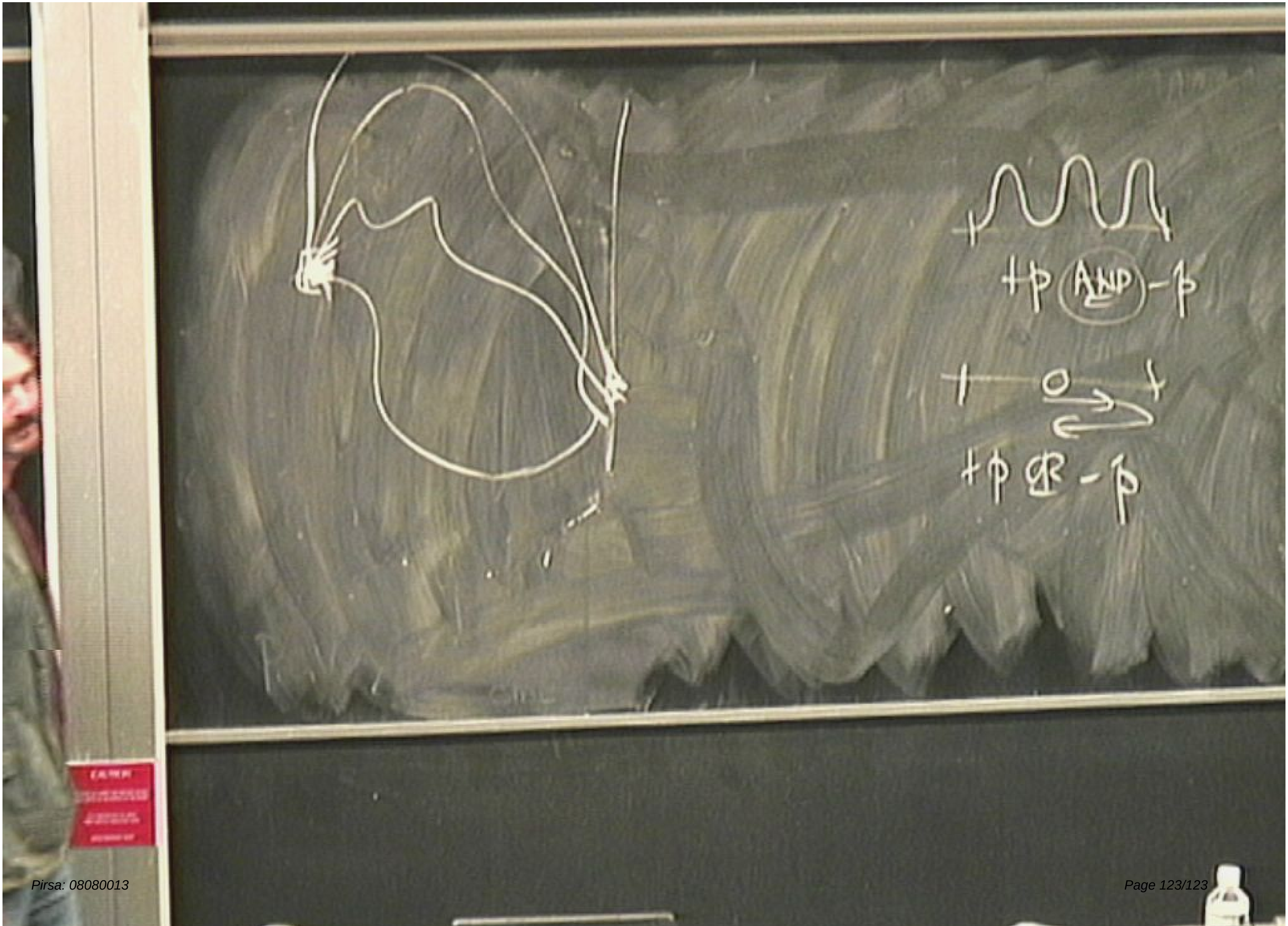
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0
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