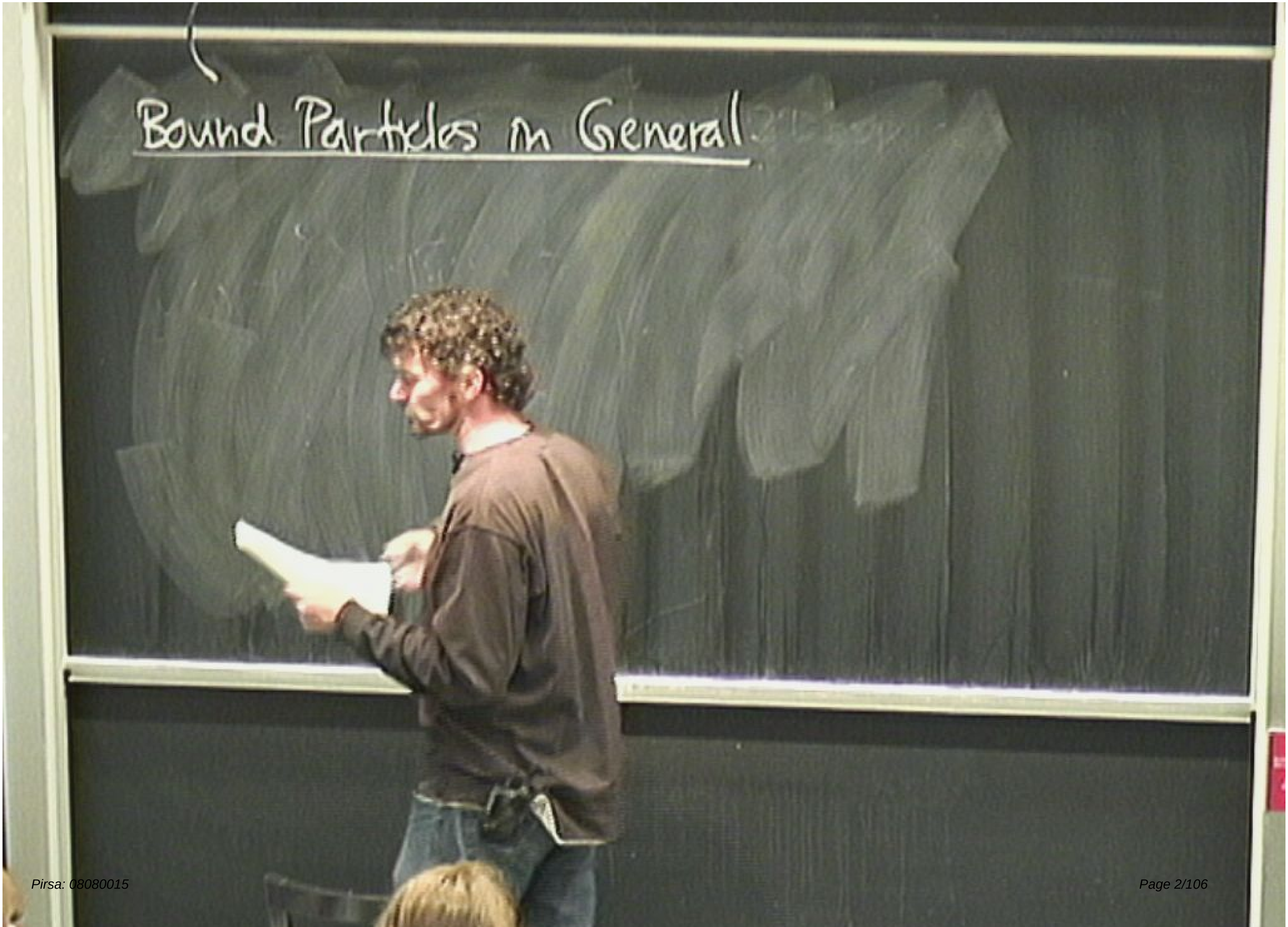
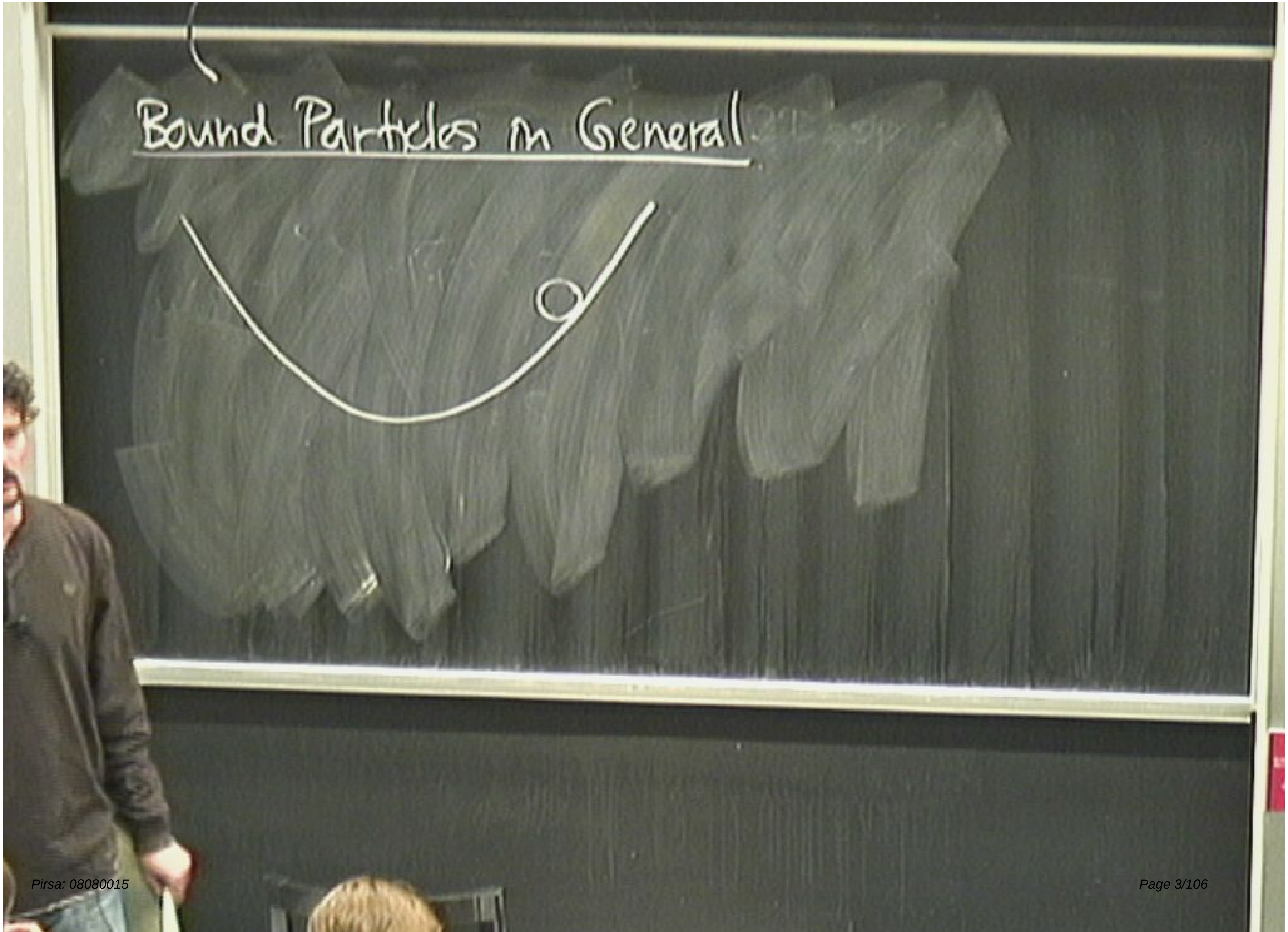
Title: Quantum 3

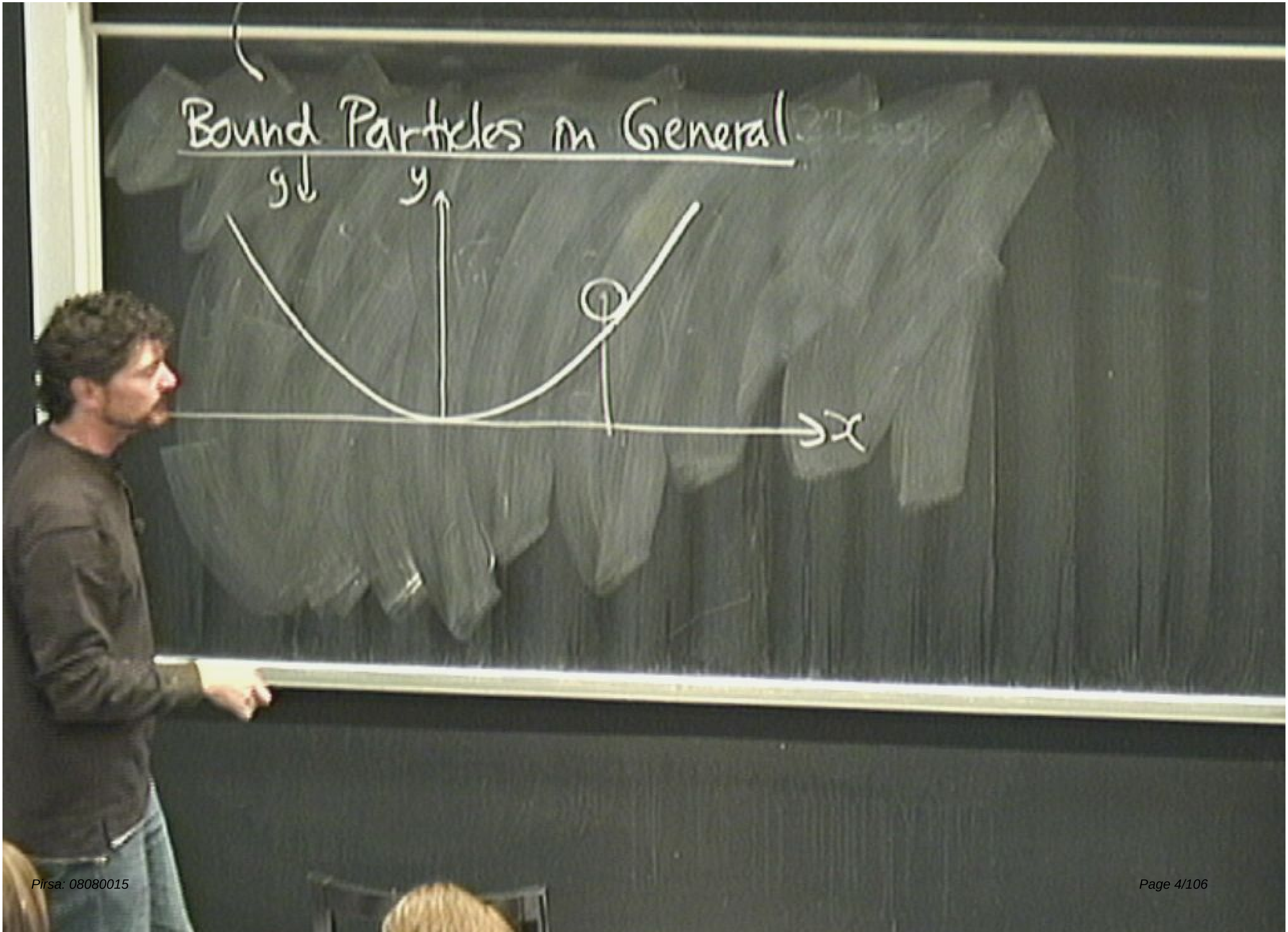
Date: Aug 12, 2008 10:30 AM

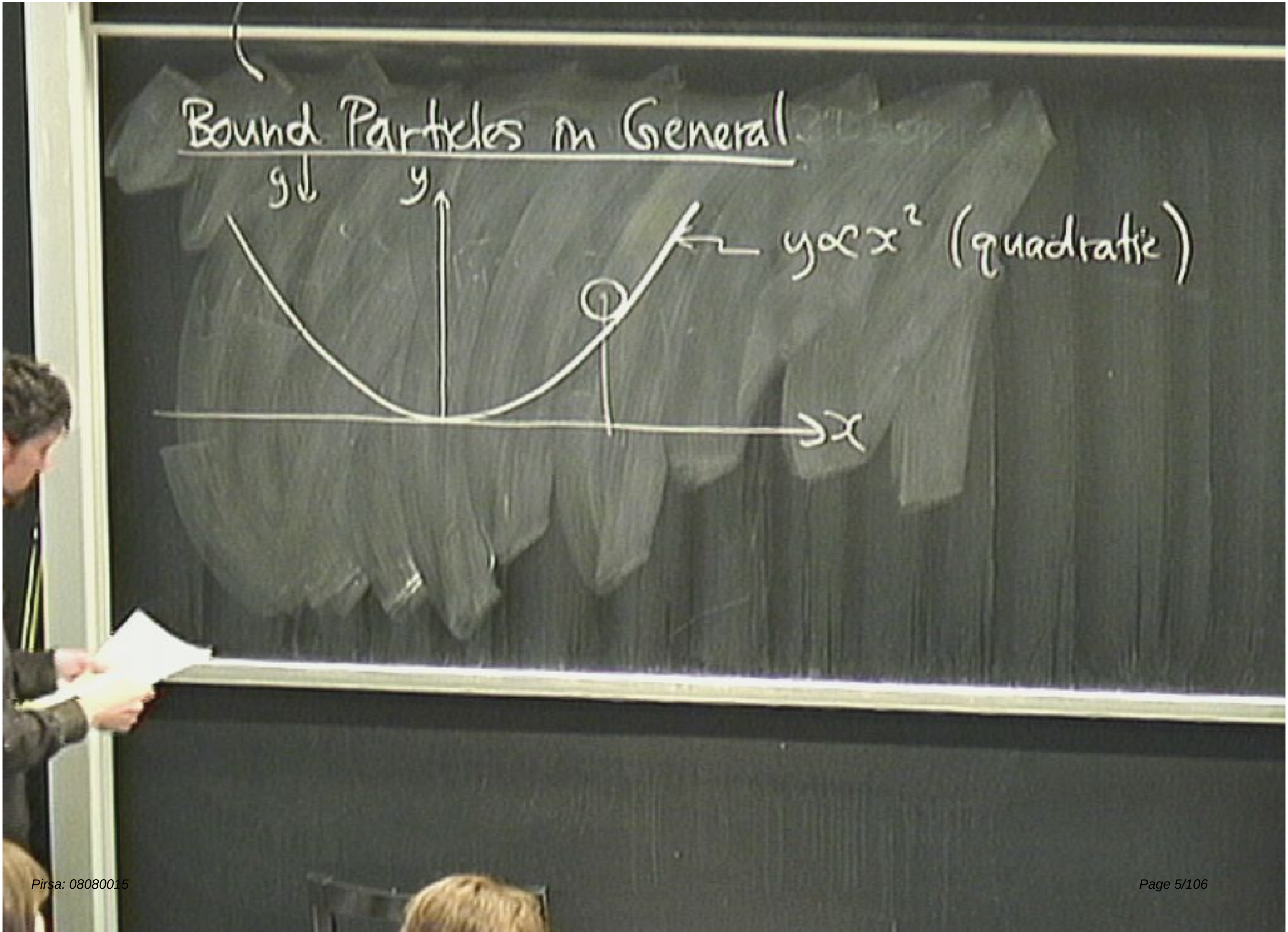
URL: http://pirsa.org/08080015

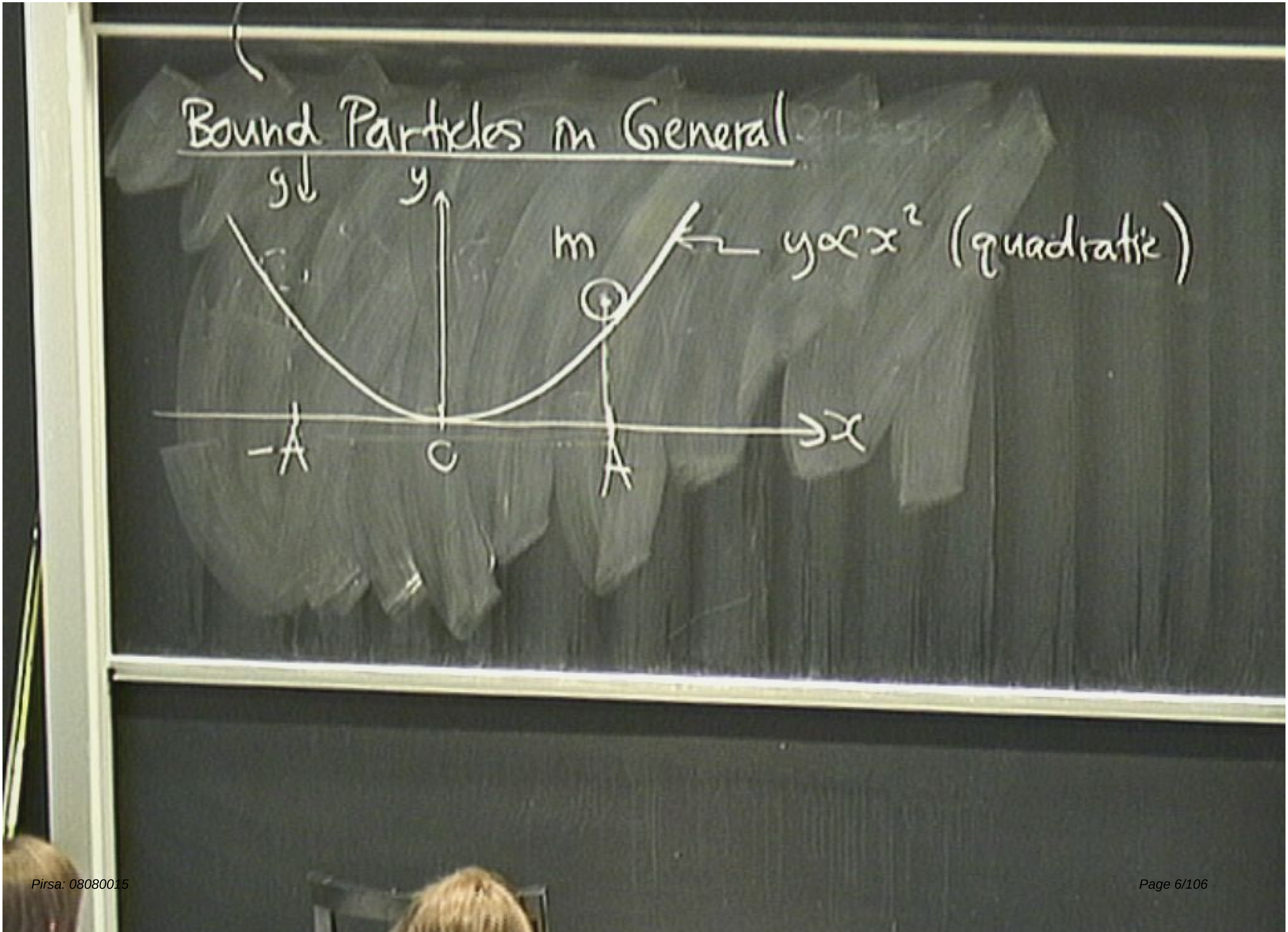
Abstract:

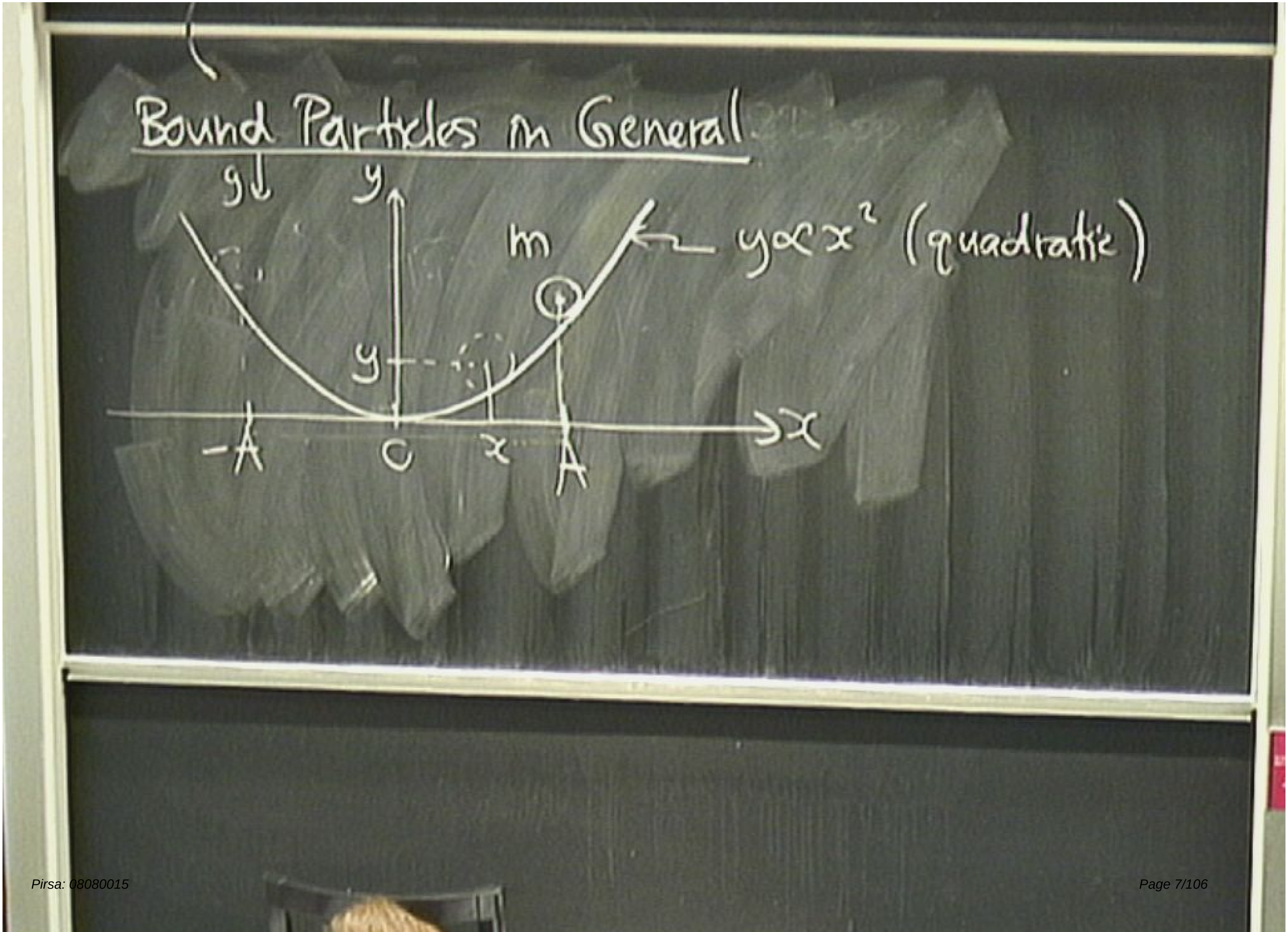

Bound Particles in General

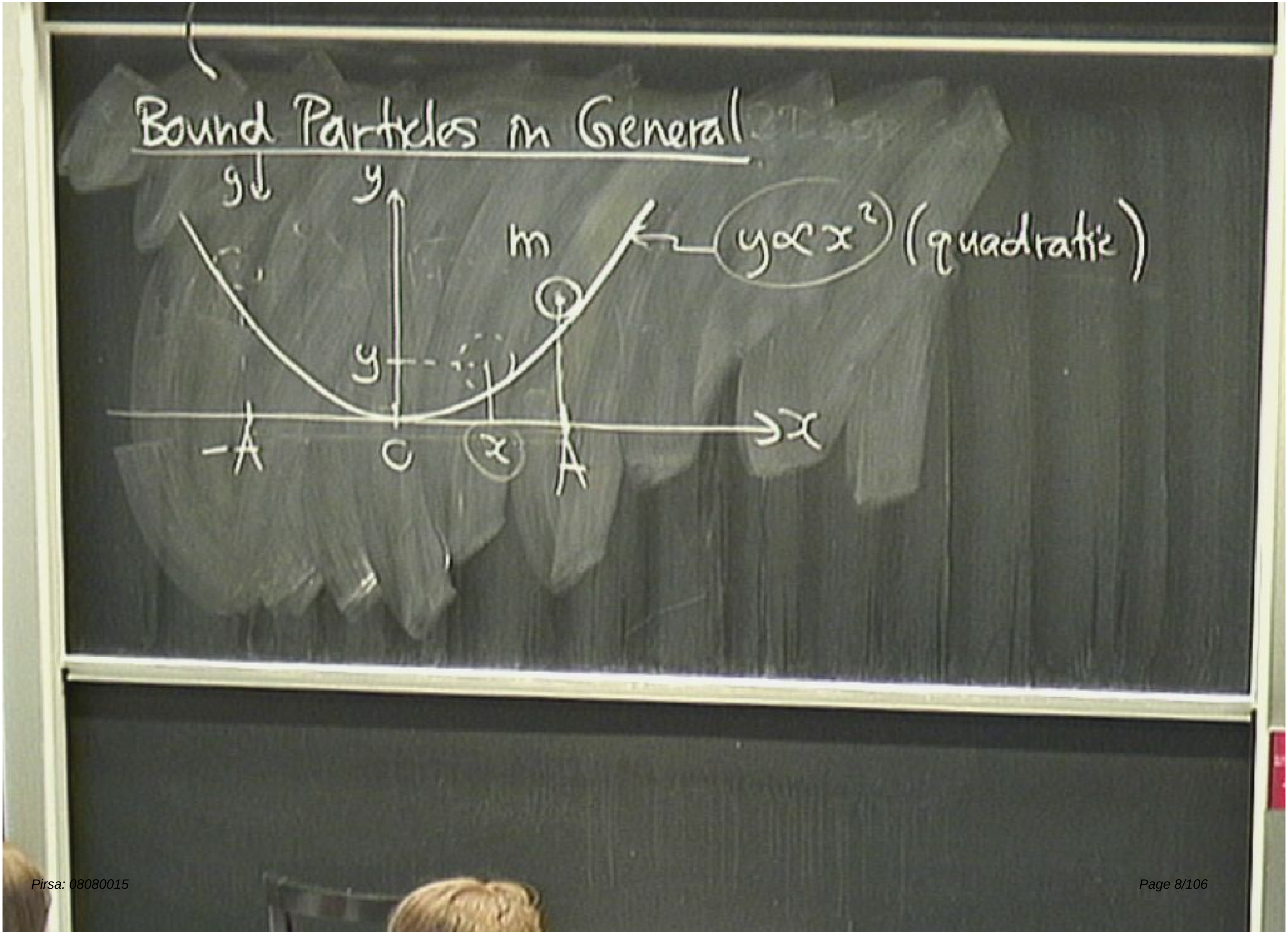

Bound Particles in General

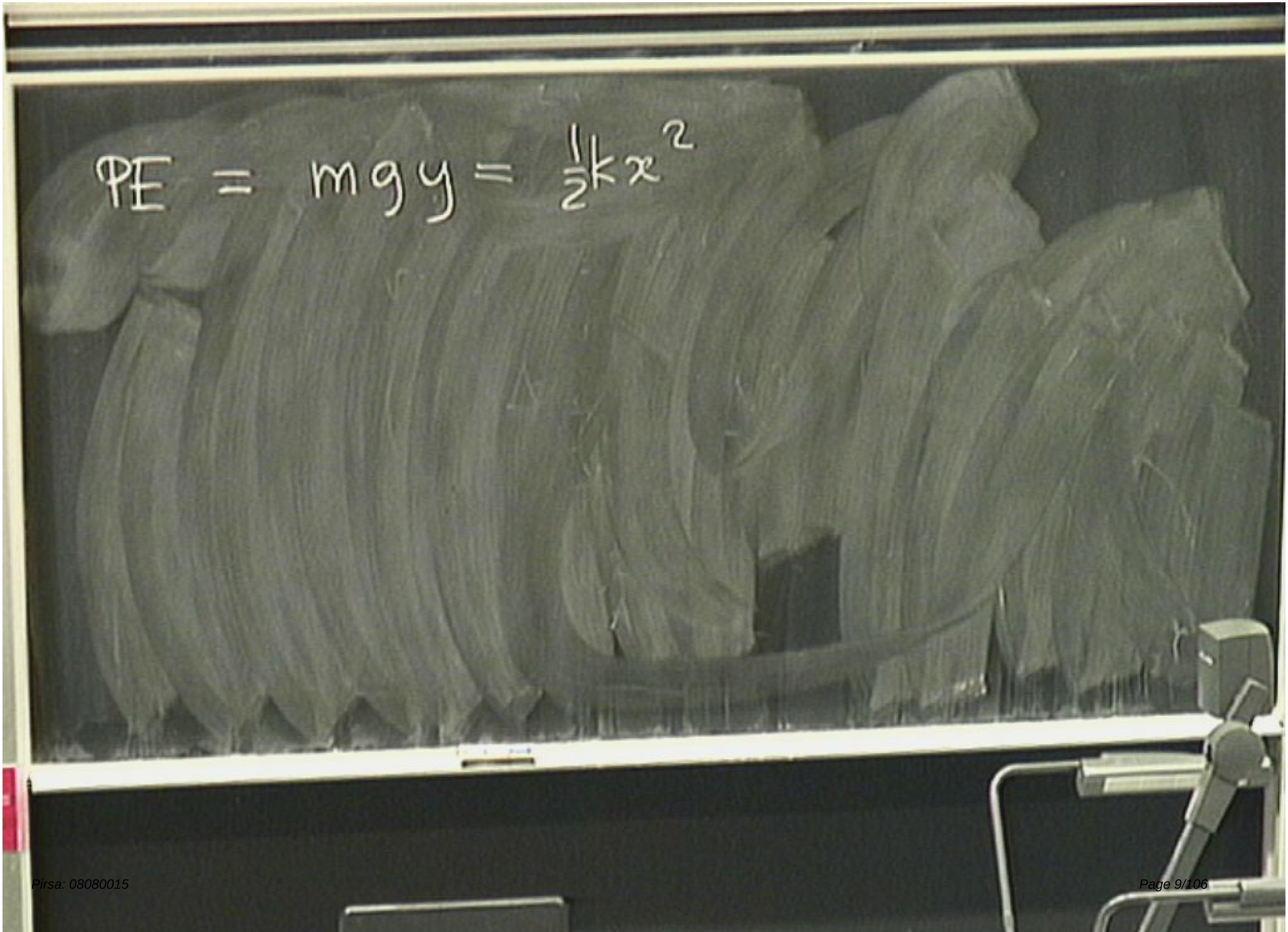

Bound Particles in General
g
y
x

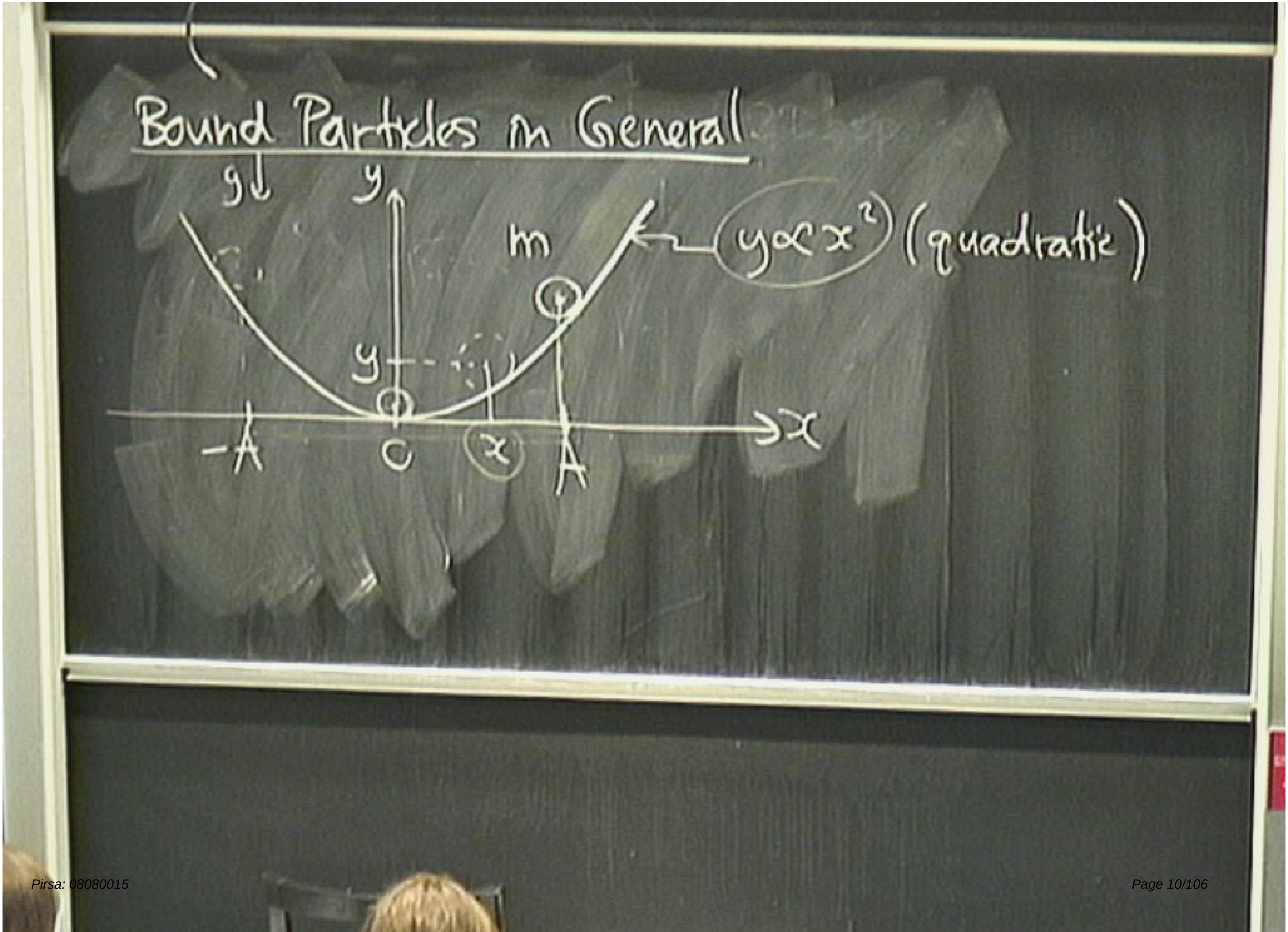

Bound Particles in General
g
y
$y \propto x^2$ (quadratic)
x


Bound Particles in General
g
y
m
$y \propto x^2$ (quadratic)
-A
0
A
x


Bound Particles in General
g
y
m
y ∝ x² (quadratic)
y
x
−A
0
x
A


Bound Particles in General
g
y
m
y ∝ x² (quadratic)
y
−A
0
x
A
x


PE = mgy = ½kx²

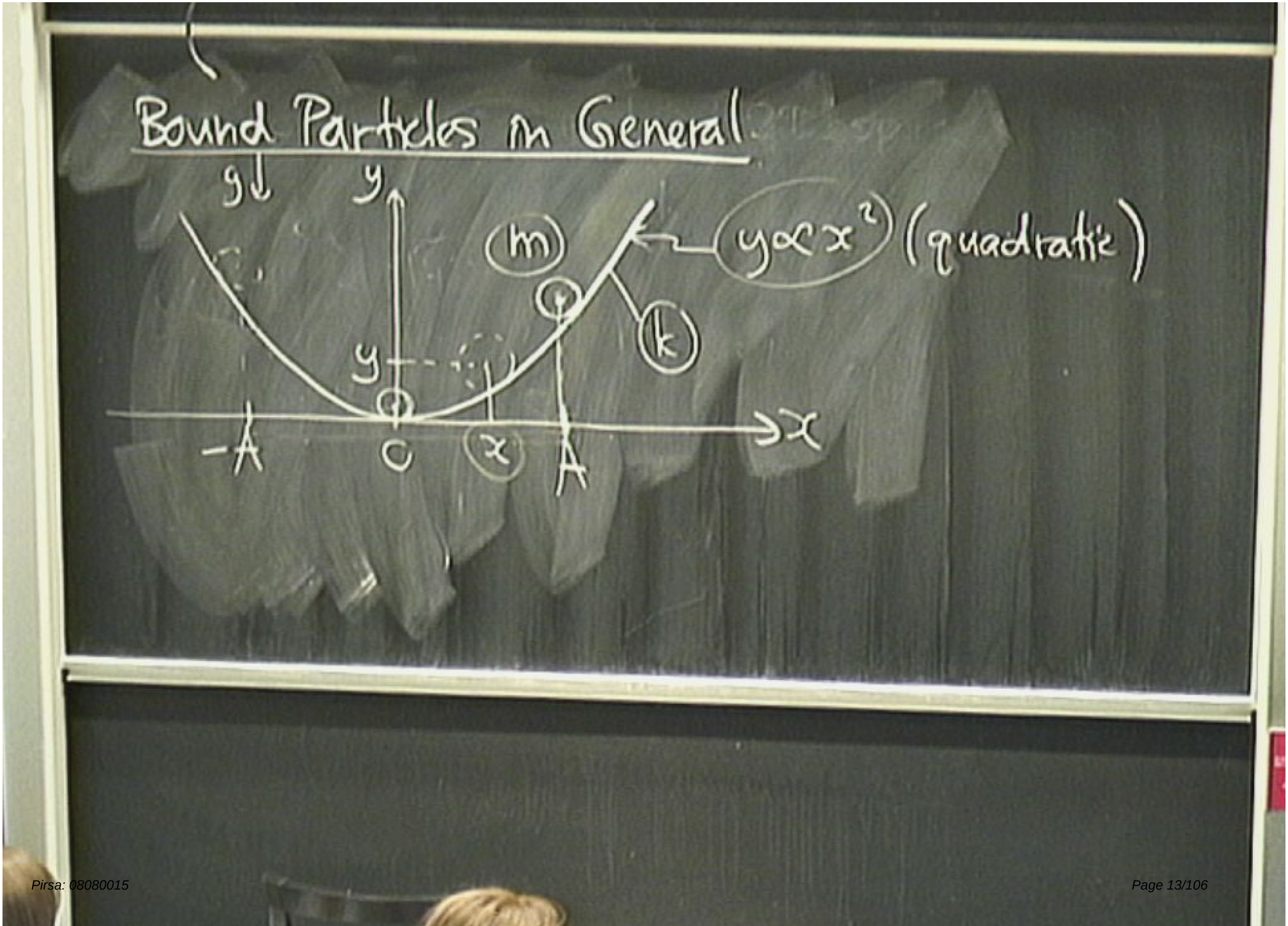

Bound Particles in General
g
y
m
y ∝ x²
(quadratic)
y
-A
0
x
A
x

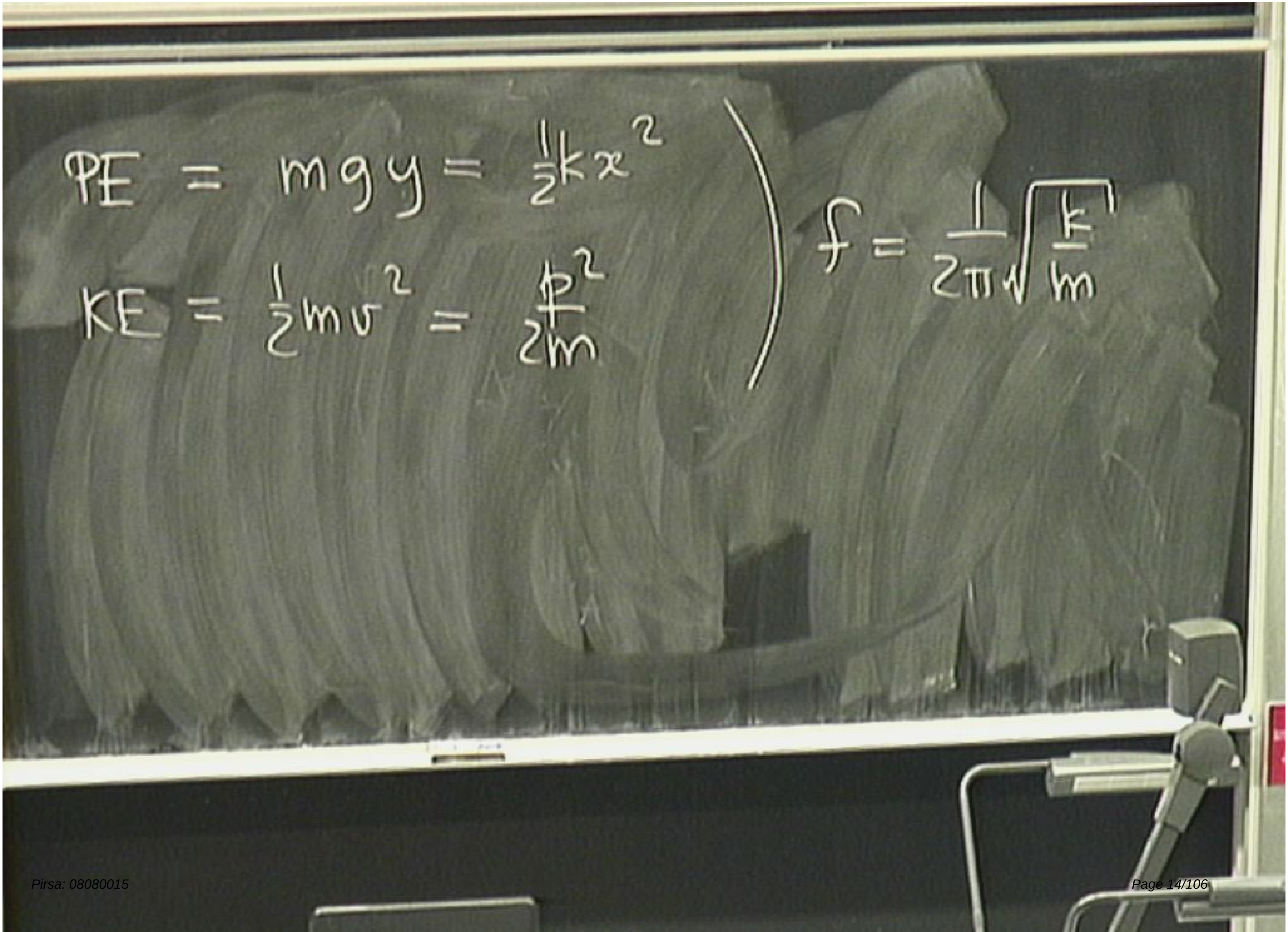
$$PE = mgy = \frac{1}{2}kx^2$$

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

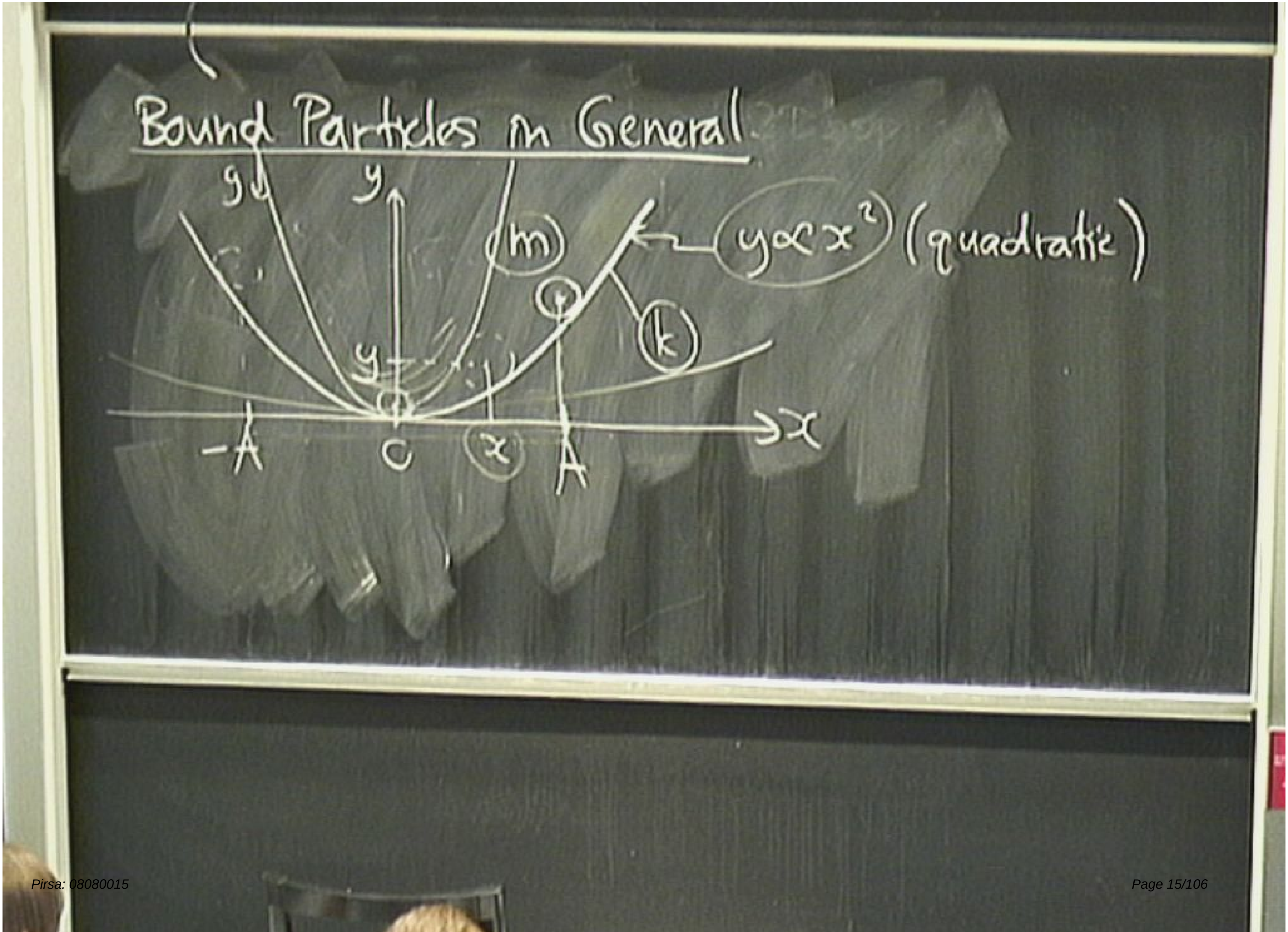
$$PE = mgy = \frac{1}{2}kx^2$$

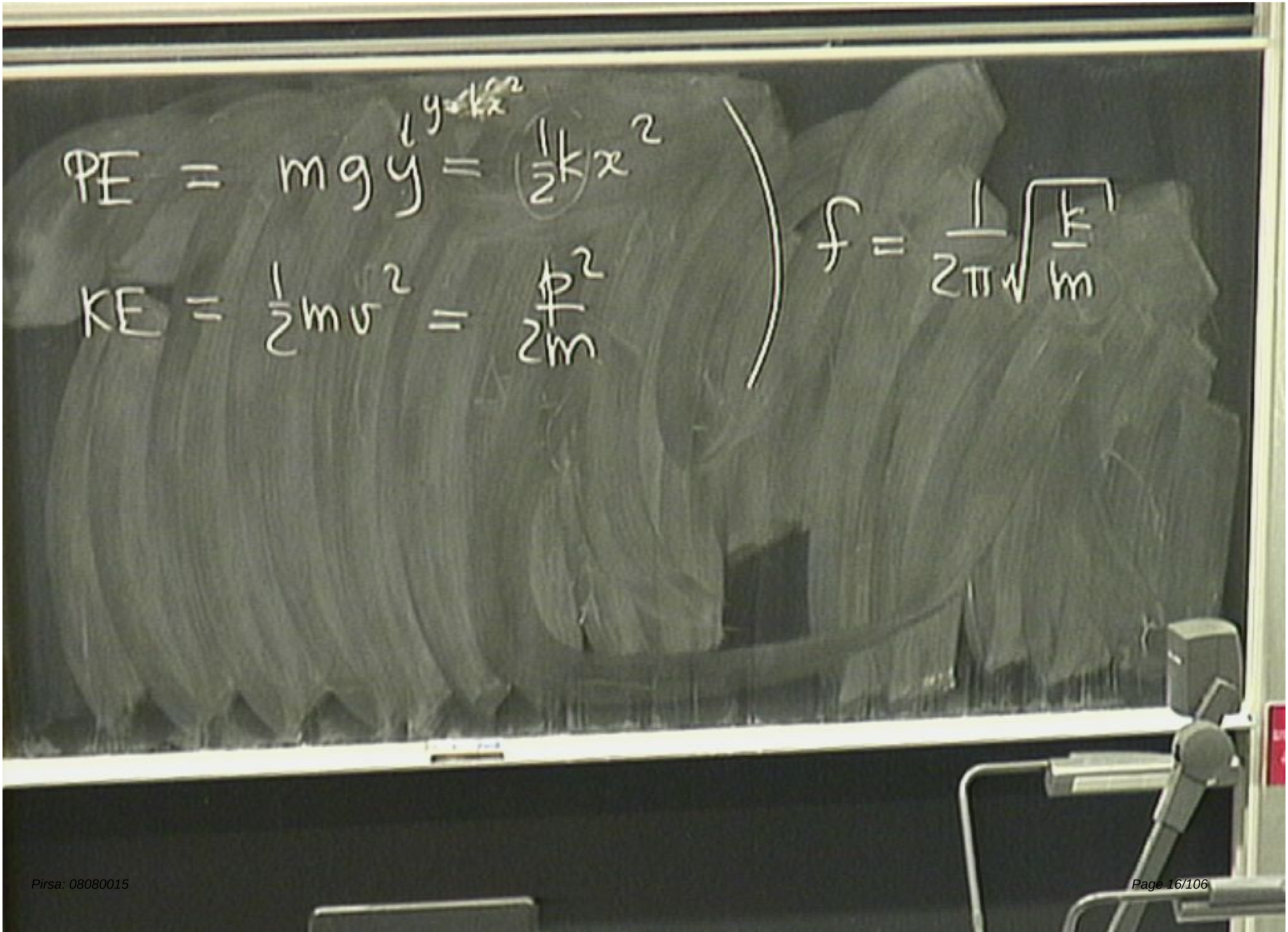
$$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

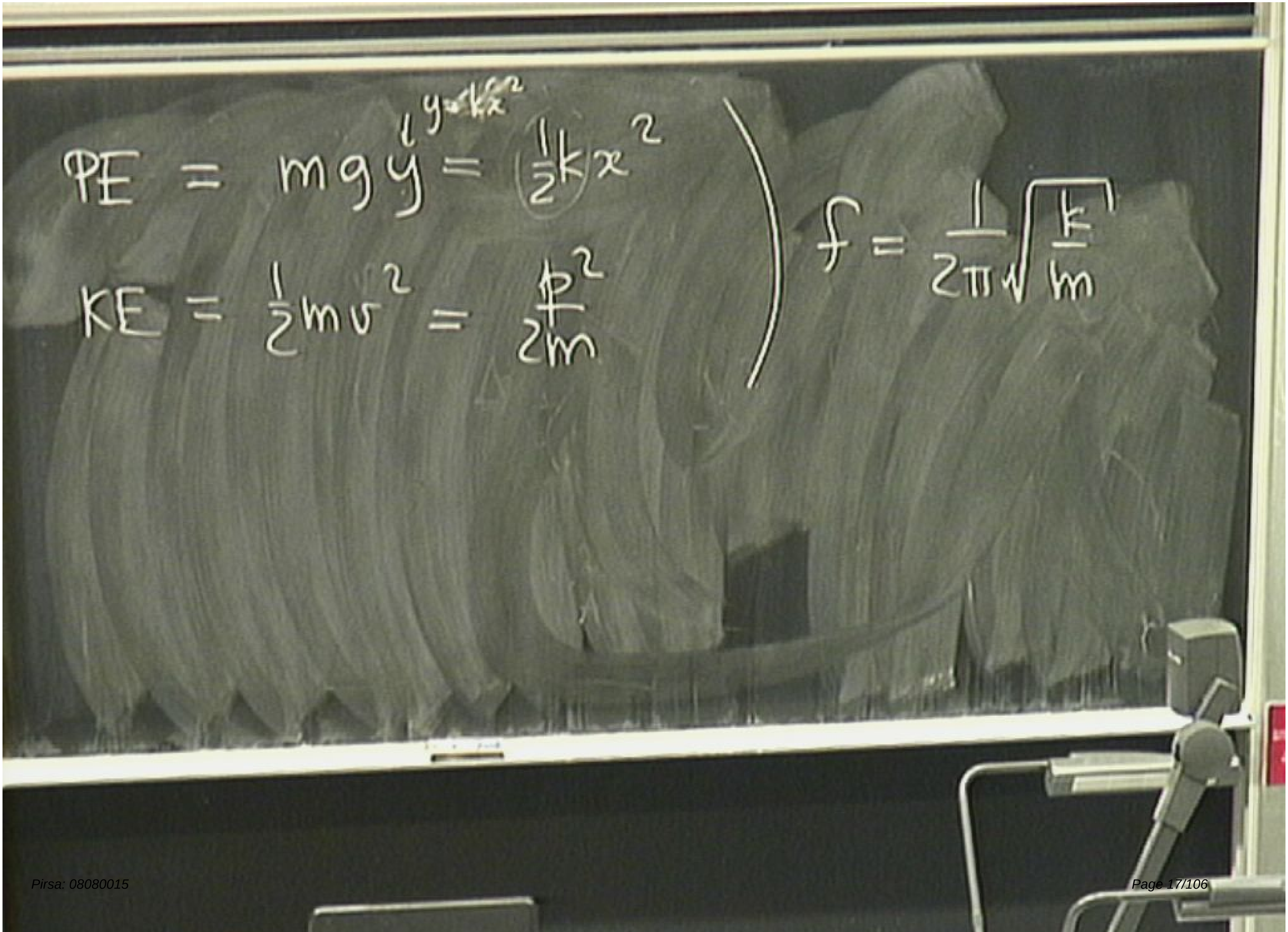

Bound Particles in General
g
y
y
m
k
$y \propto x^2$ (quadratic)
-A
0
x
A
x

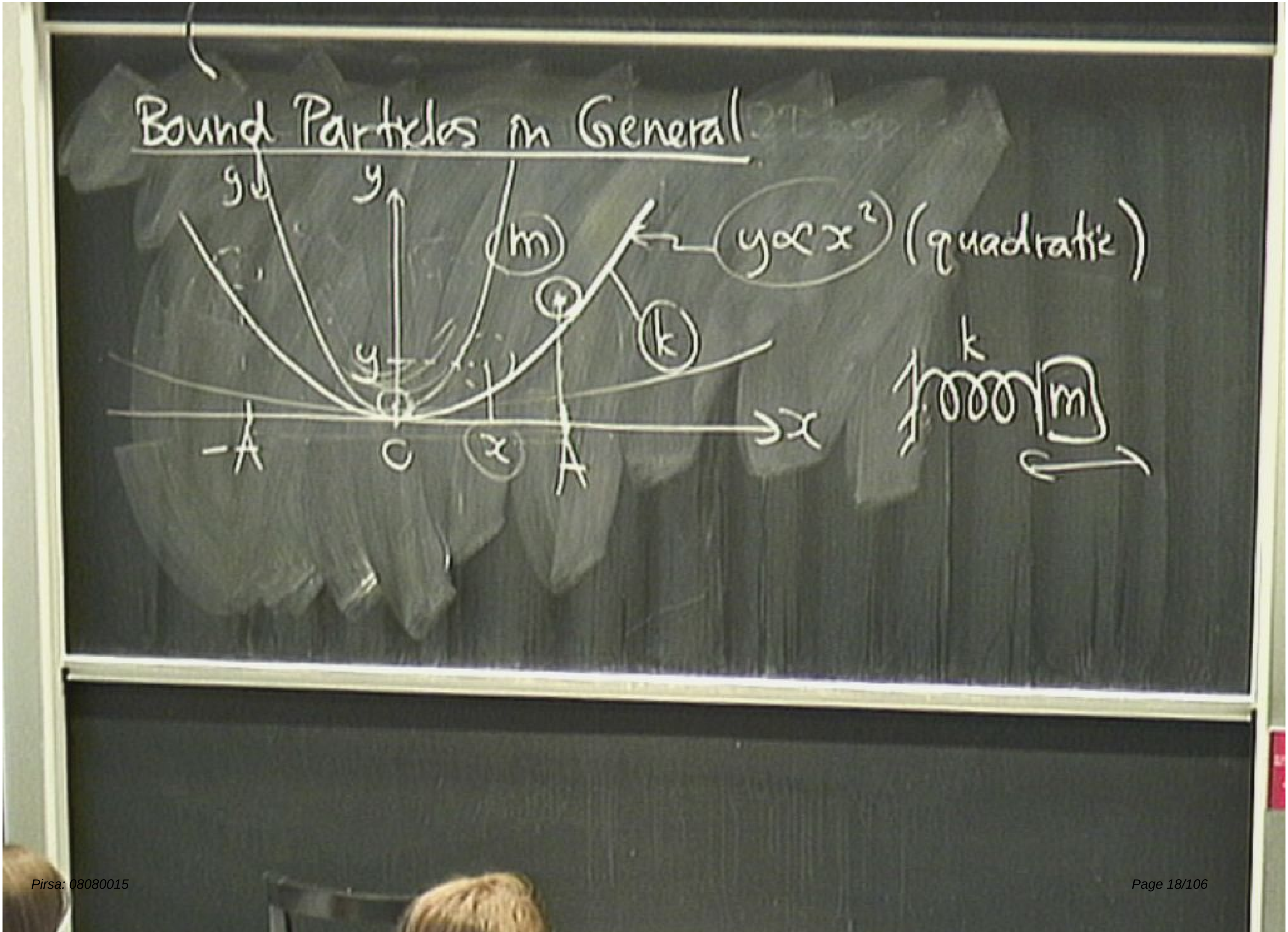


$PE = mgy = \frac{1}{2}kx^2$
$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$


Bound Particles in General
g
y
m
y ∝ x² (quadratic)
k
y
x
-A
O
x
A


$y = kx^2$
$PE = mgy = \frac{1}{2}kx^2$
$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$


$PE = mgy = \frac{1}{2}kx^2$
$y = kx^2$
$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$


Bound Particles in General
y
y
(m)
$y \propto x^2$ (quadratic)
(k)
k
m
x
-A
0
x
A

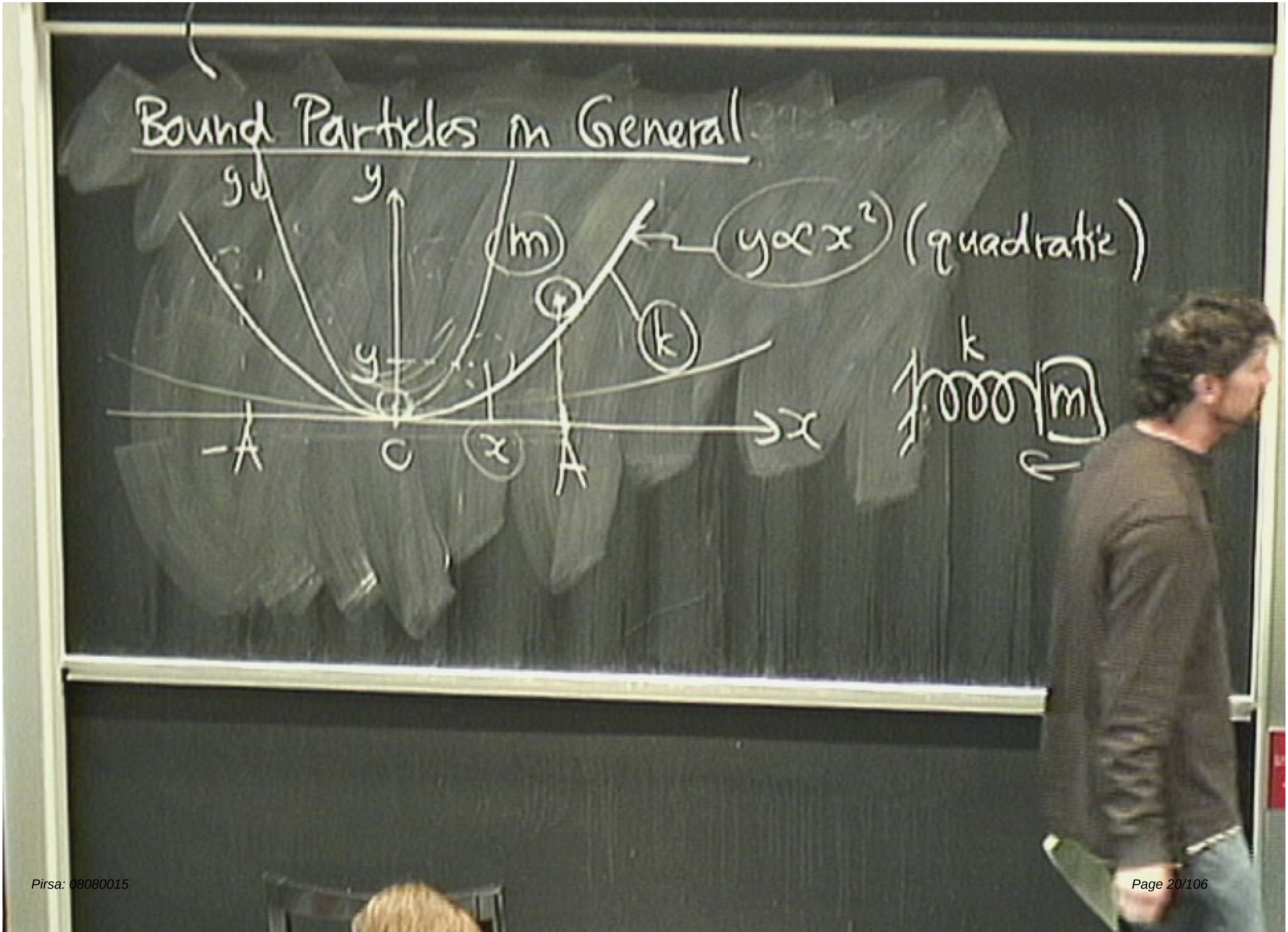
$$y = kx^2$$

$$PE = mgy = \frac{1}{2}kx^2$$

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

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$E = KE + PE = \frac{p^2}{2m} + \frac{1}{2}kx^2$$



Bound Particles in General
y
m
y ∝ x²
(quadratic)
k
y
-A
0
x
A
x
k
m

$$PE = mgy = \frac{1}{2}kx^2$$

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

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$E = KE(t) + PE(t) = \frac{p^2}{2m} + \frac{1}{2}kx^2$$

↑ constant

$$PE = mgy = \frac{1}{2}kx^2$$

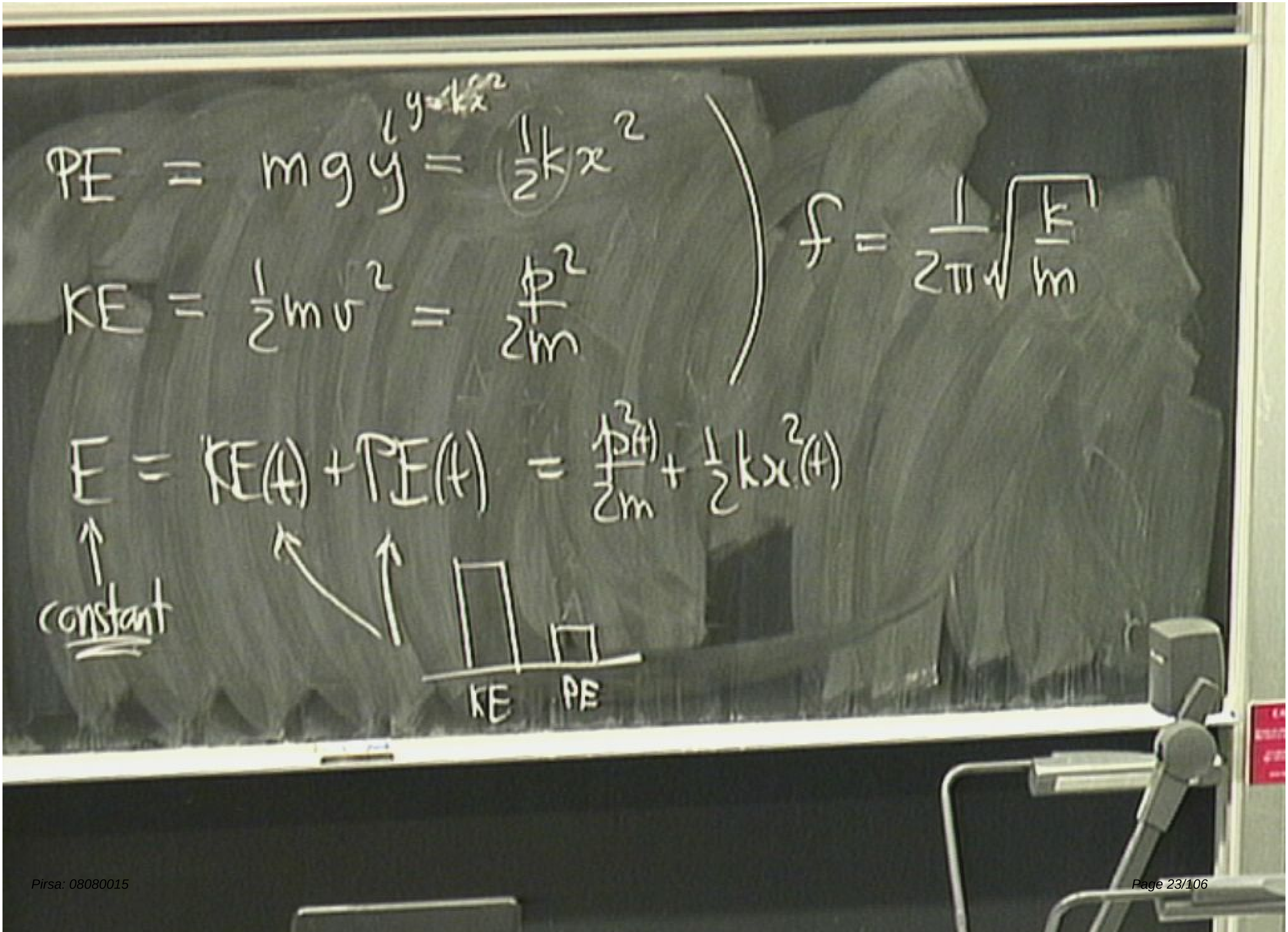
($y = kx^2$)

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

$$f = \frac{1}{2\pi\sqrt{\frac{k}{m}}}$$

$$E = KE(t) + PE(t) = \frac{p^2(t)}{2m} + \frac{1}{2}kx^2(t)$$

↑ constant


$PE = mgy = \frac{1}{2}kx^2$
$y = \frac{1}{2}kx^2$
$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$
$E = KE(t) + PE(t) = \frac{p^3(t)}{2m} + \frac{1}{2}kx^2(t)$
constant
KE
PE

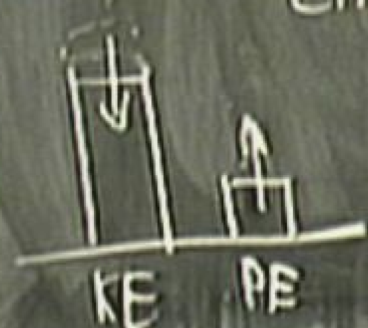
$$PE = mgy = \frac{1}{2}kx^2$$

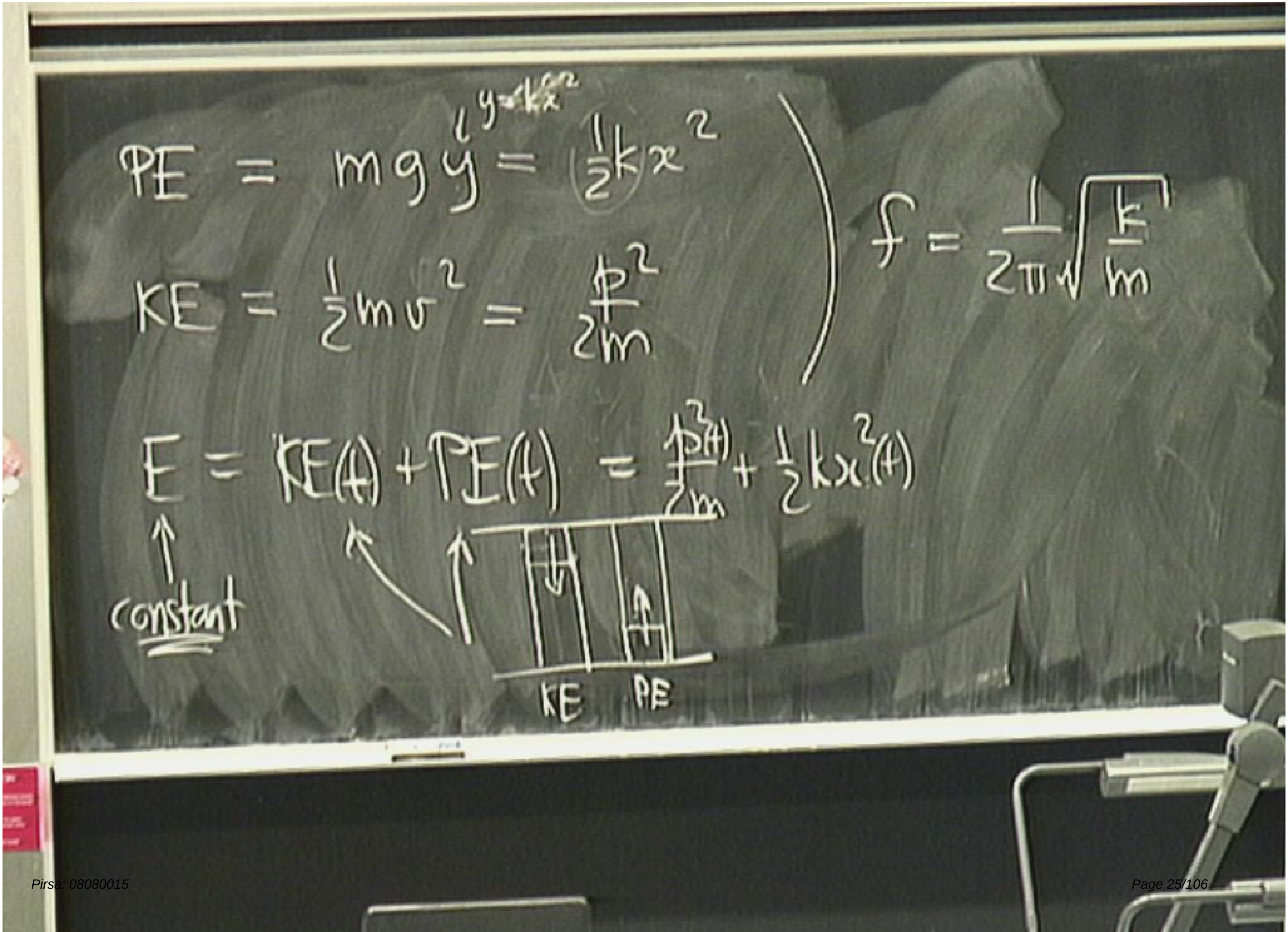
$$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

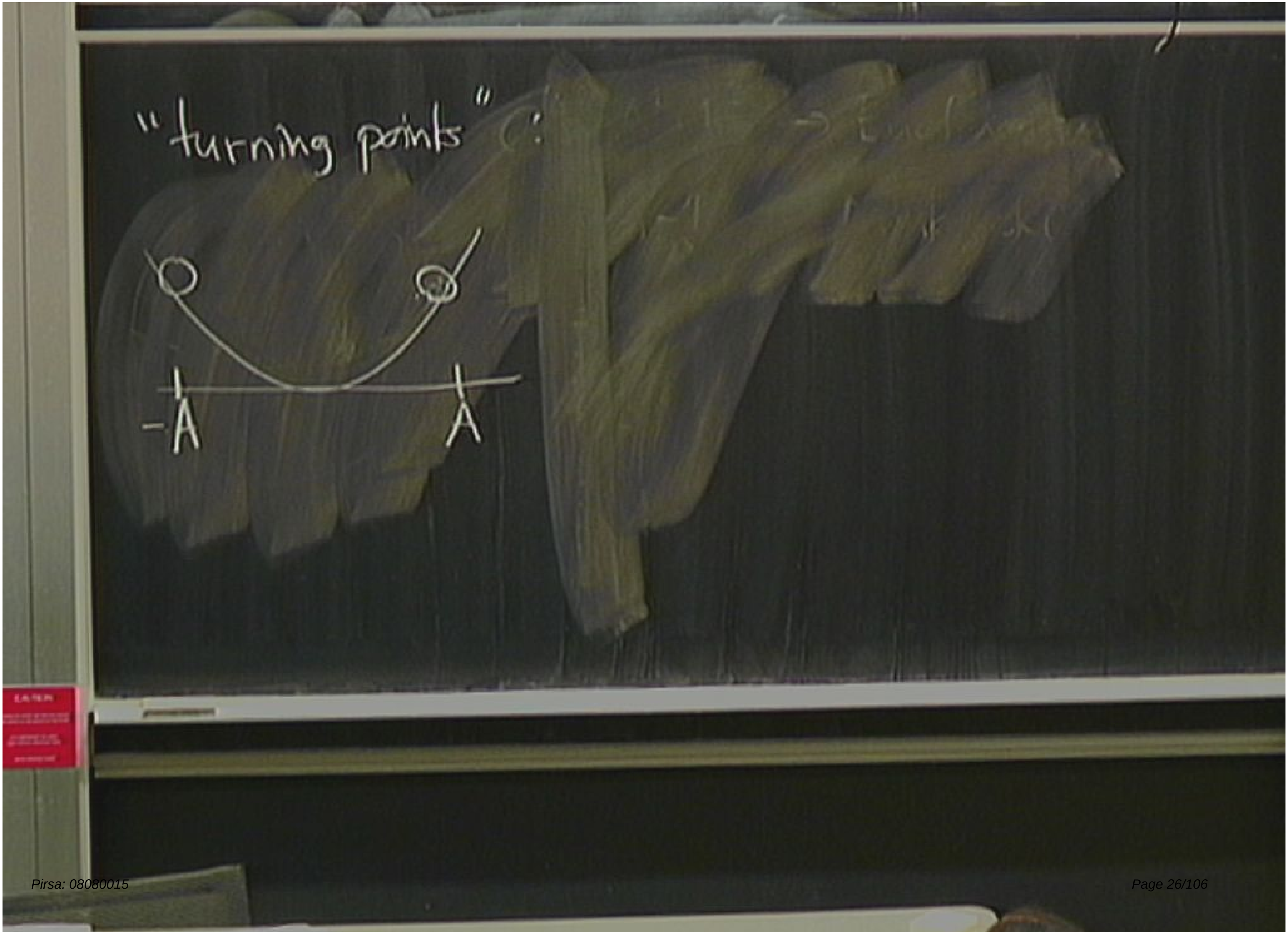
$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

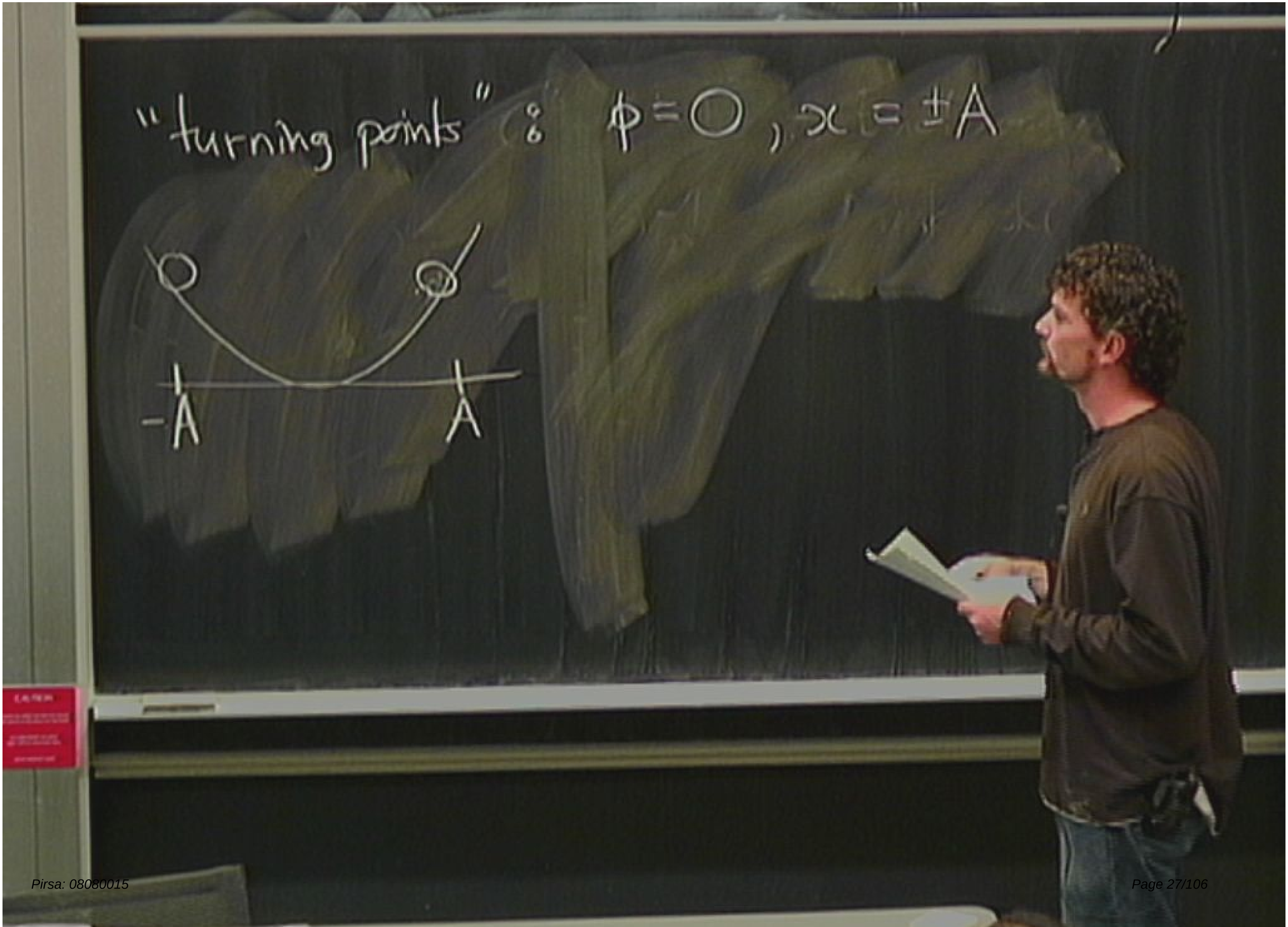
$$E = KE(t) + PE(t) = \frac{p^2(t)}{2m} + \frac{1}{2}kx^2(t)$$

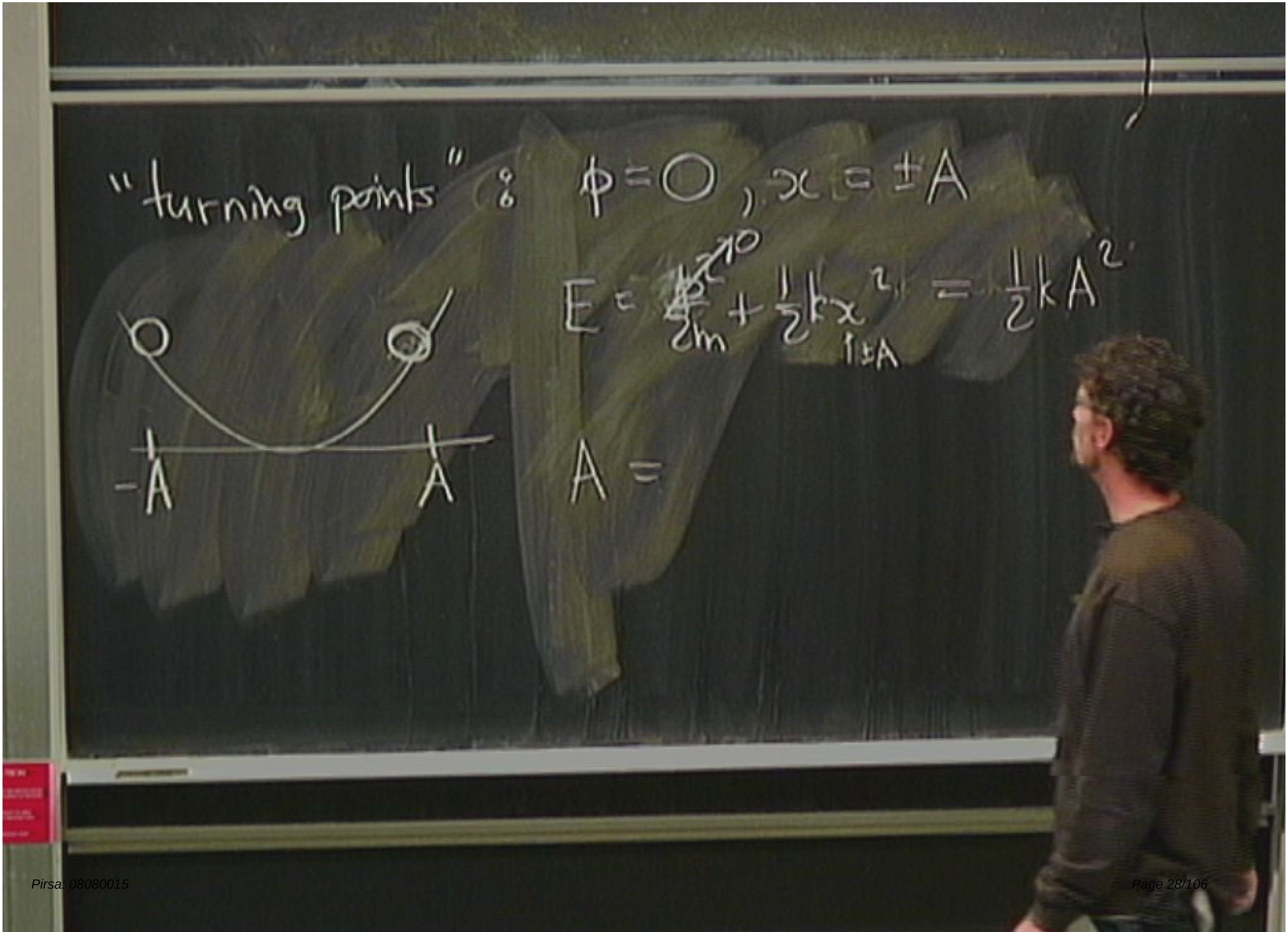
constant

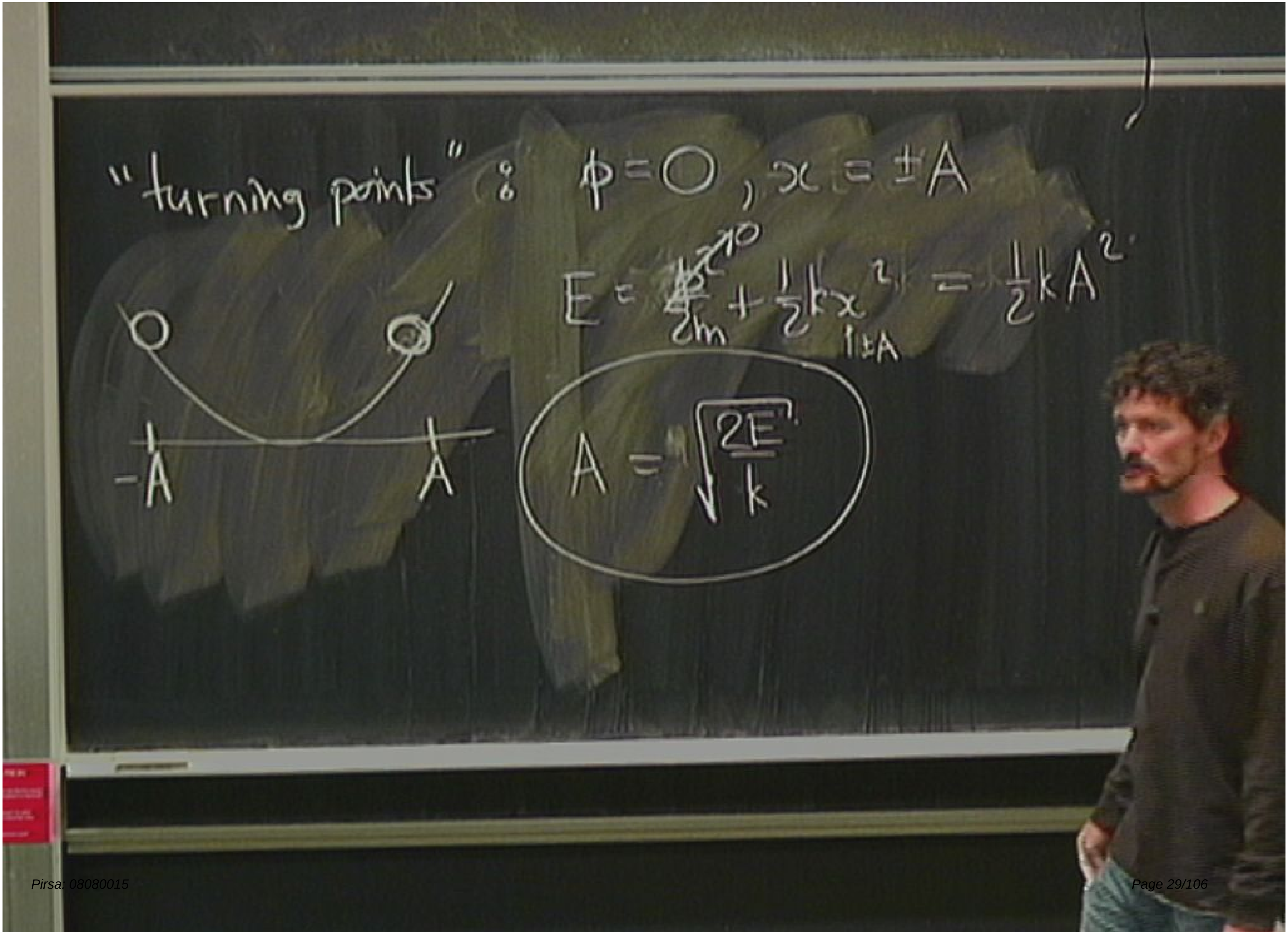


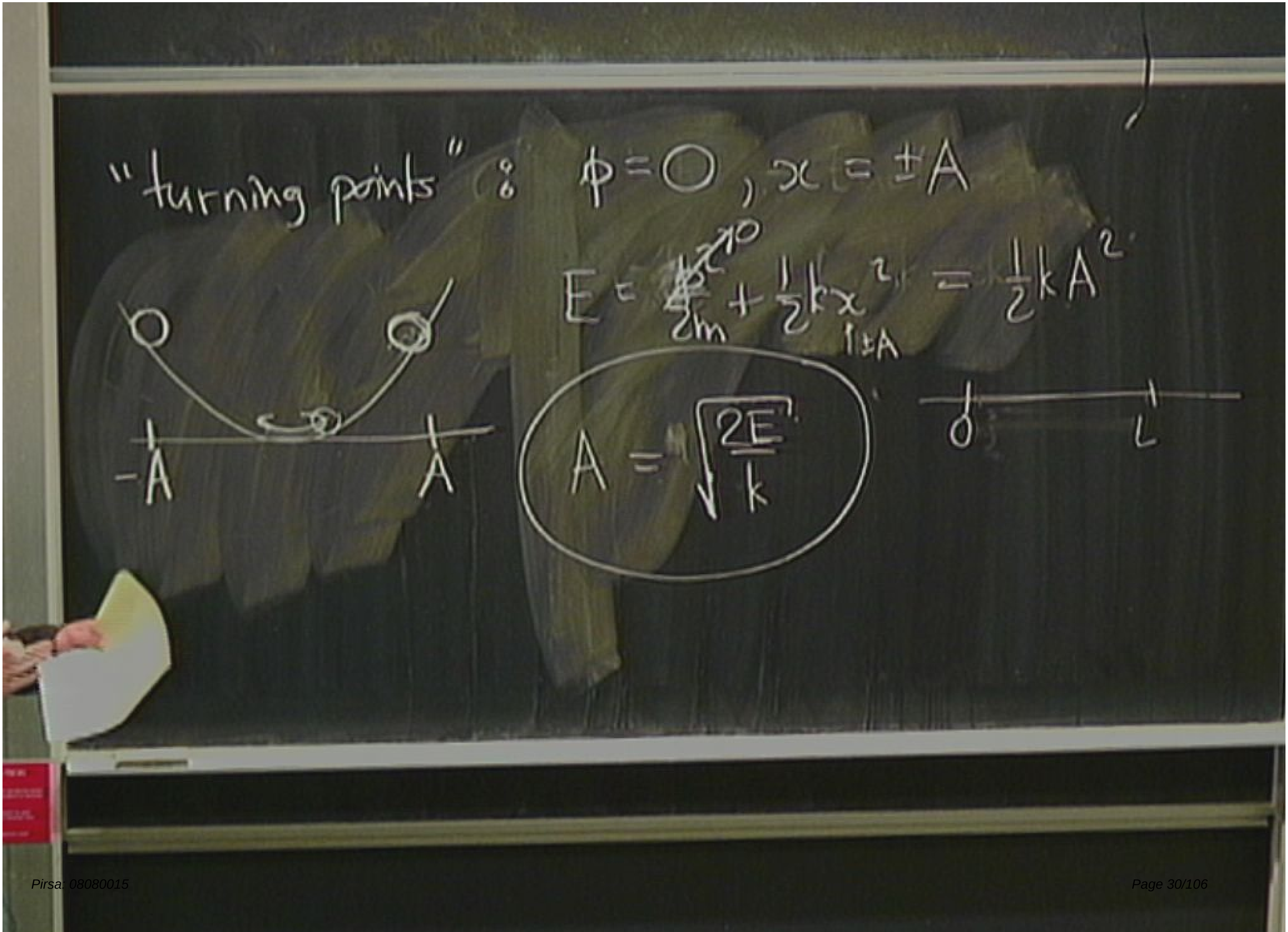

PE = mgy = 1/2 kx^2
y = kx^2
KE = 1/2 mv^2 = p^2/2m
f = 1/2π √(k/m)
E = KE(t) + PE(t) = p^2(t)/2m + 1/2 kx^2(t)
constant
KE
PE

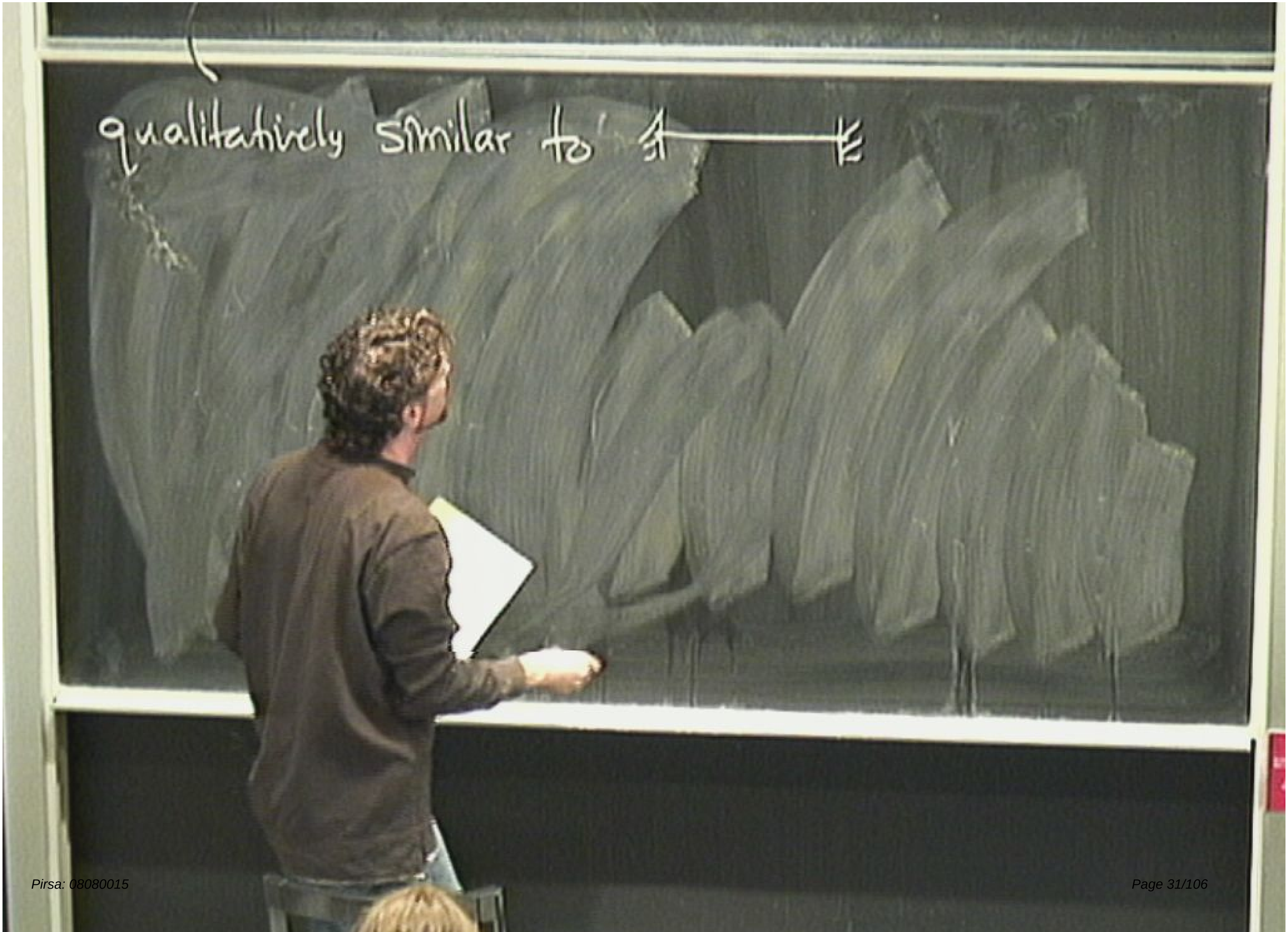

"turning points"
-A
A

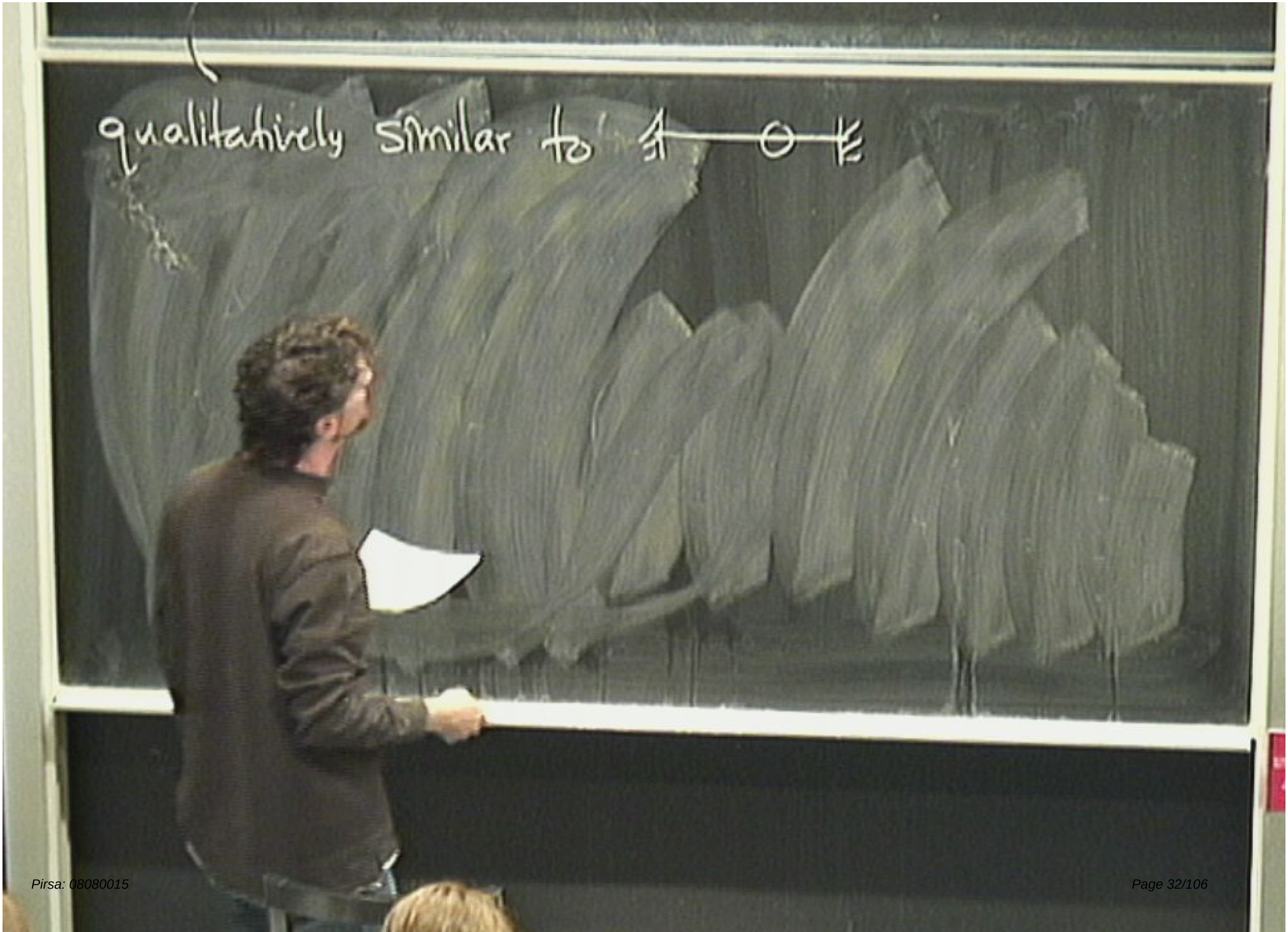

"turning points": $\dot{\phi}=0$, $x=\pm A$
$-A$
A

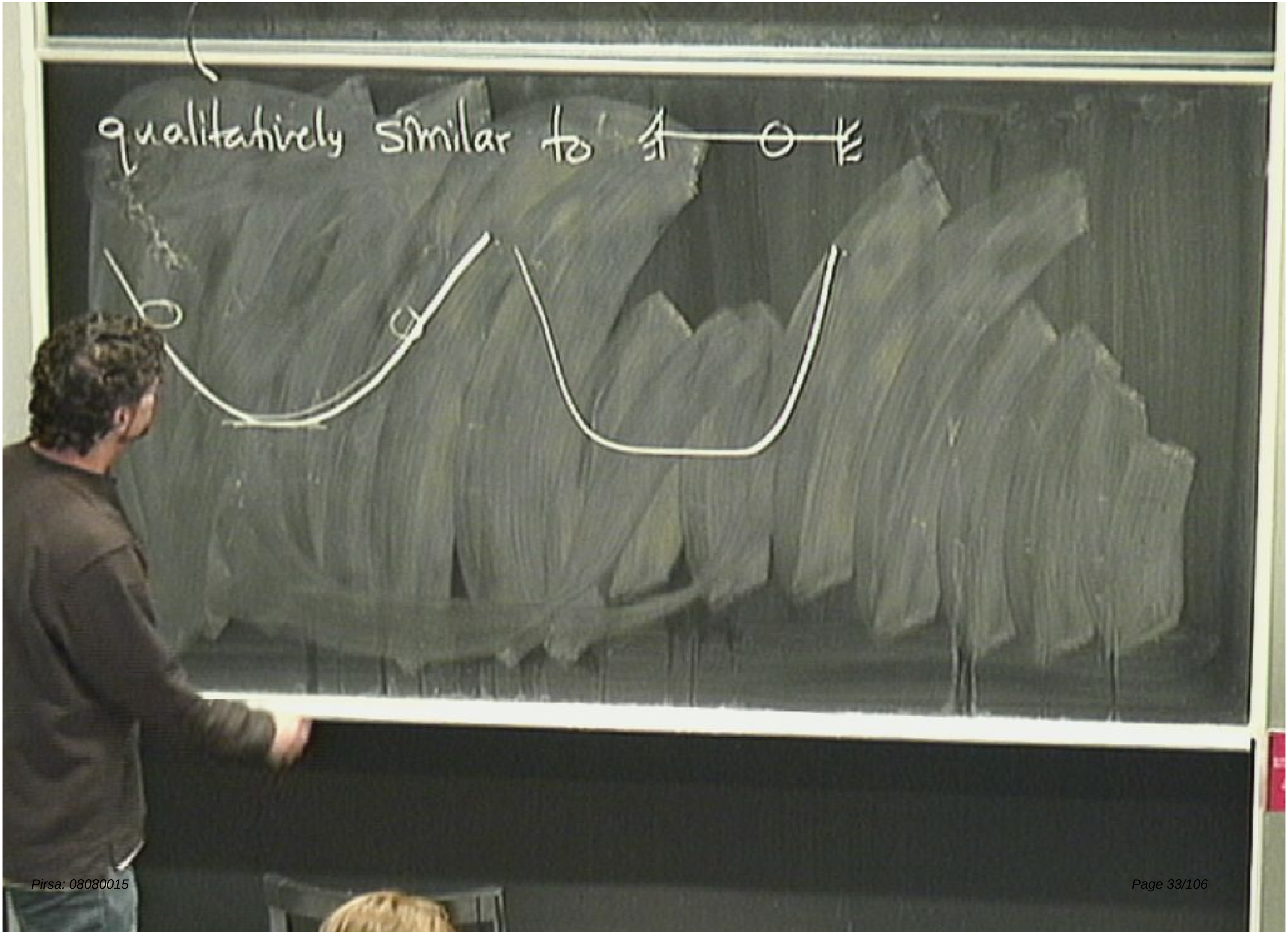

"turning points": φ = 0 , x = ±A
E = p²/2m + ½kx² = ½kA²
±A
-A
A
A =

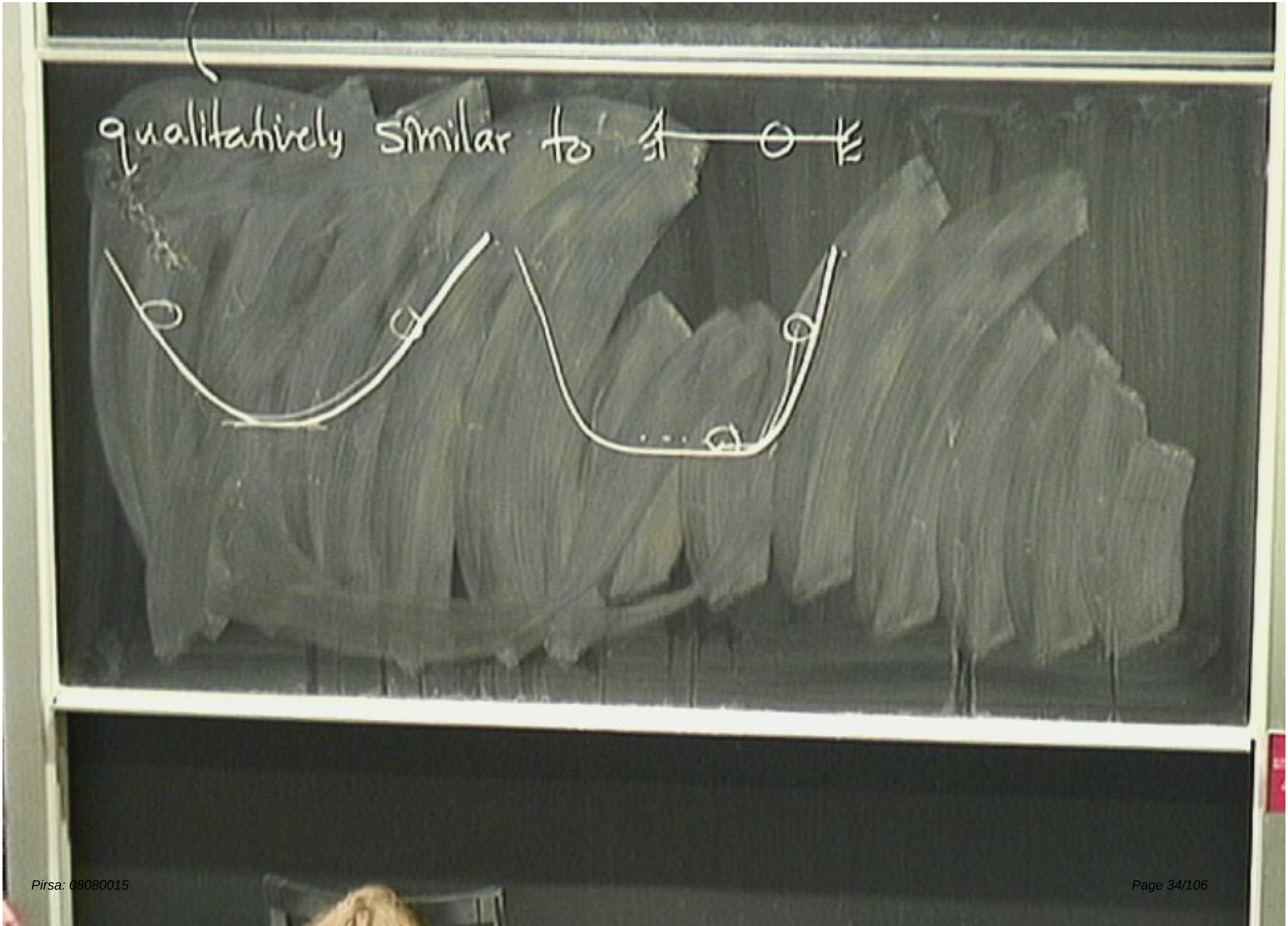

"turning points": $p=0$, $x=\pm A$
$E = \frac{p^2}{2m} + \frac{1}{2}kx^2 = \frac{1}{2}kA^2$
$\pm A$
$-A$
A
$A = \sqrt{\frac{2E}{k}}$

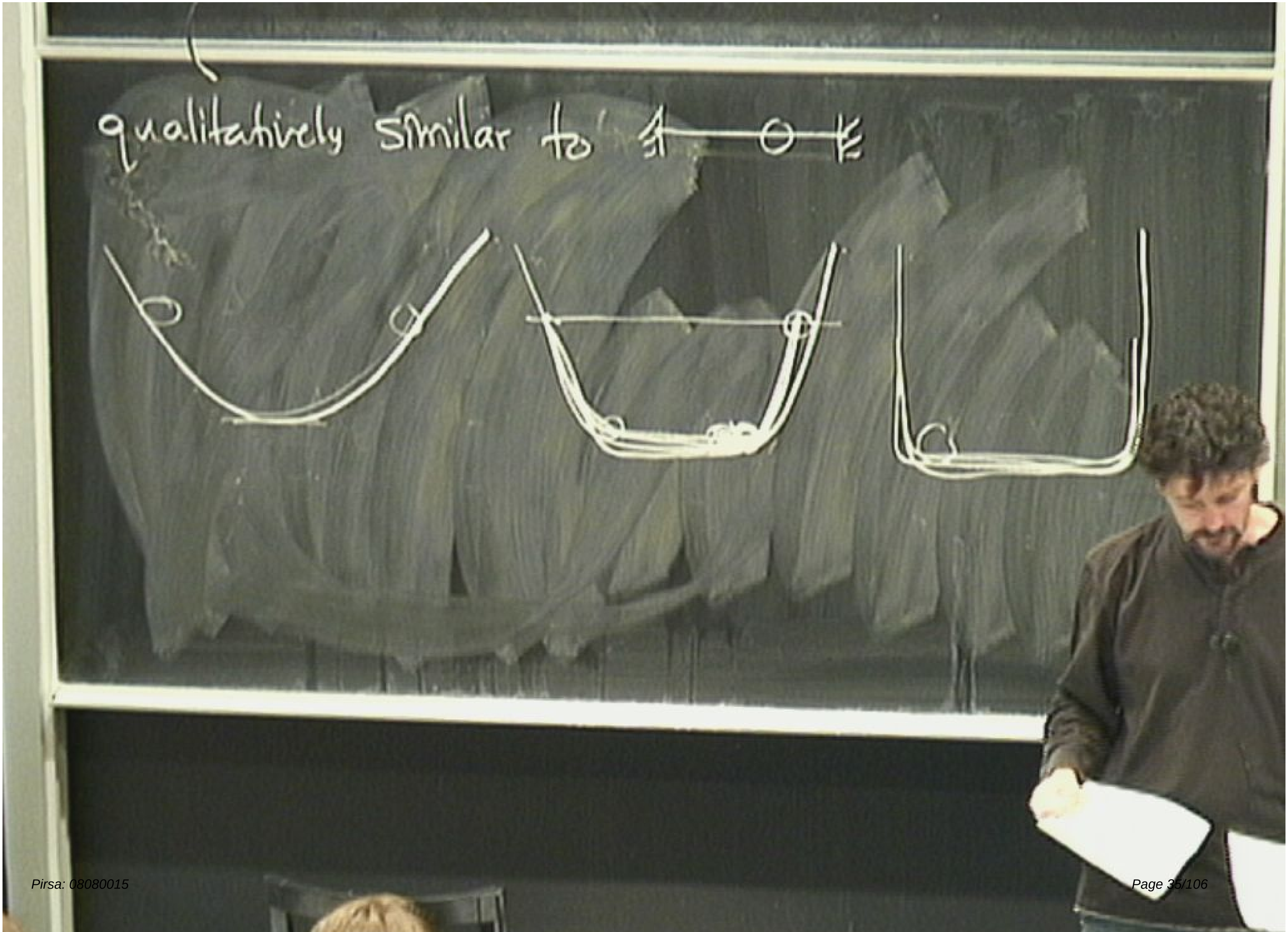

"turning points": $p = 0$, $x = \pm A$
$E = \frac{p^2}{2m} + \frac{1}{2}kx^2 = \frac{1}{2}kA^2$
$\pm A$
$-A$
A
$A = \sqrt{\frac{2E}{k}}$
0
L

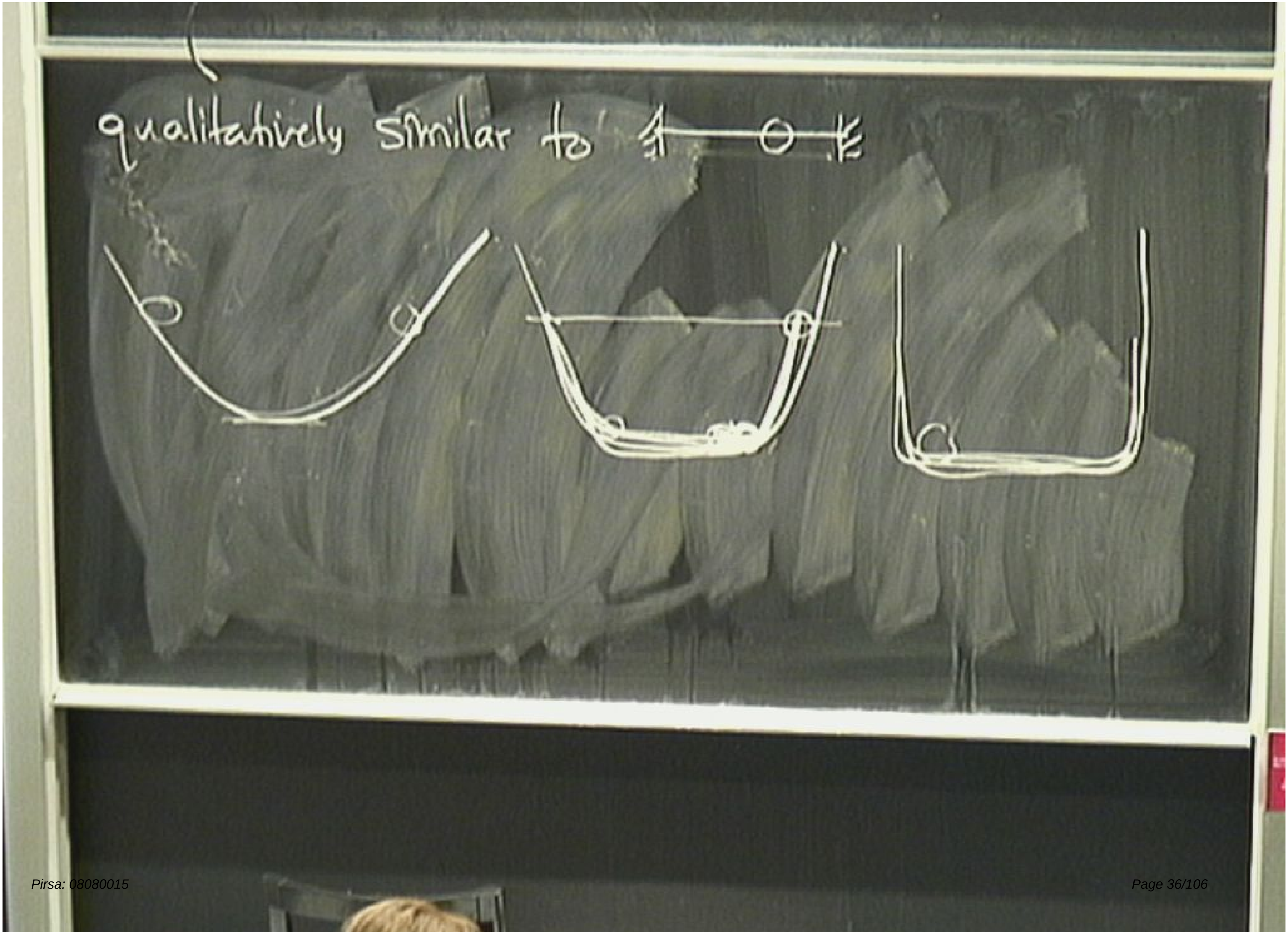

qualitatively similar to

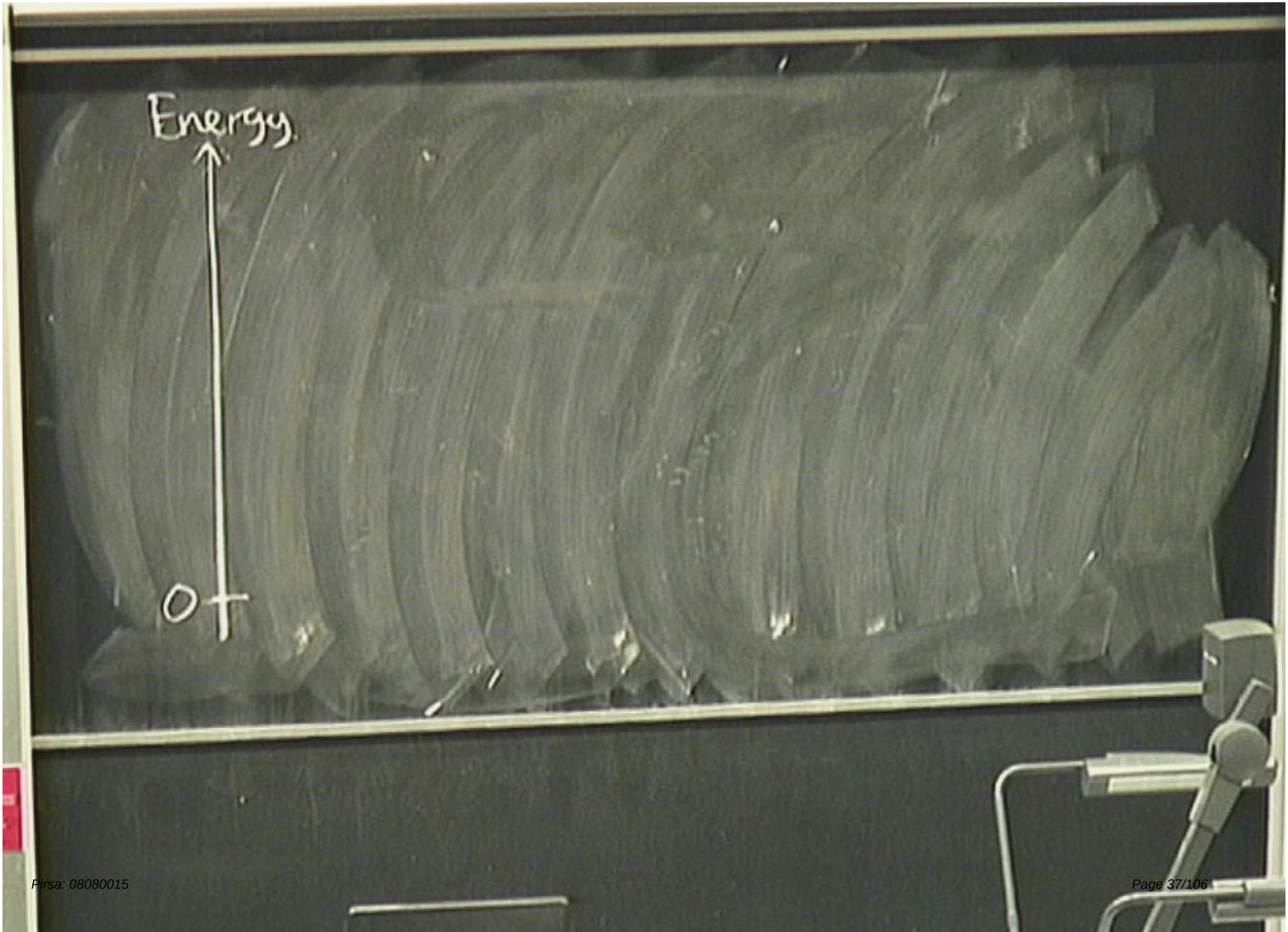

qualitatively similar to

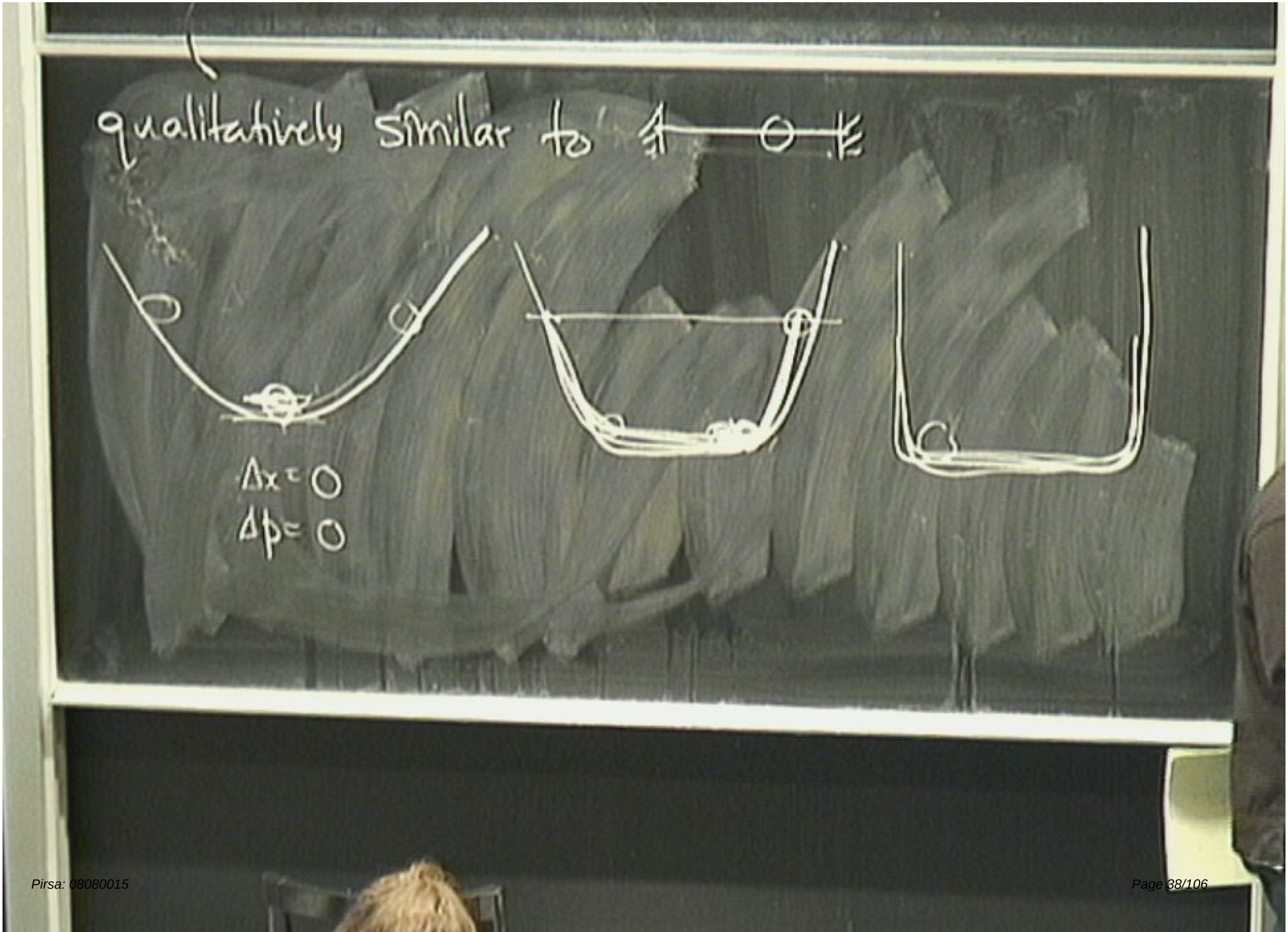

qualitatively similar to

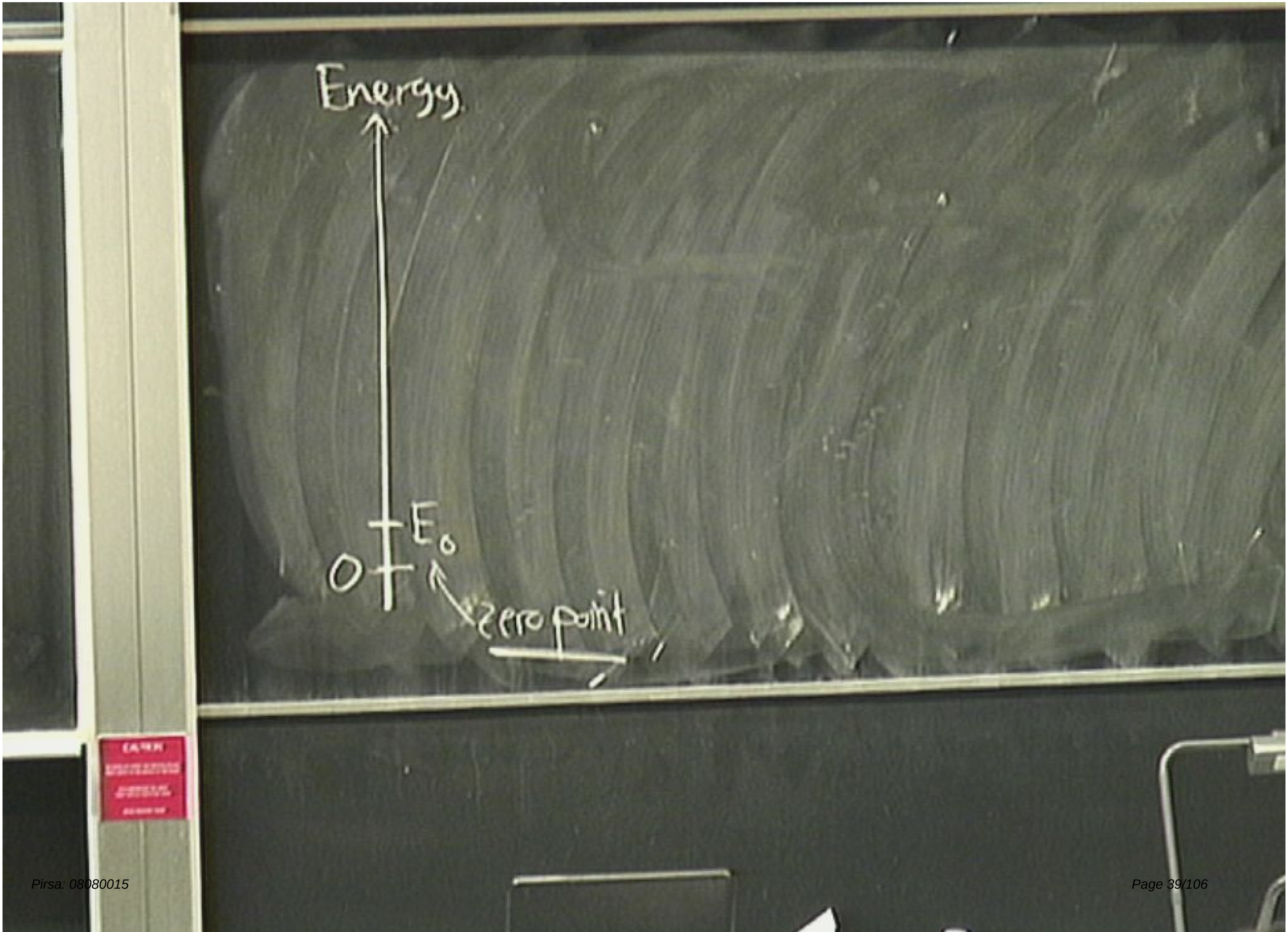

qualitatively similar to

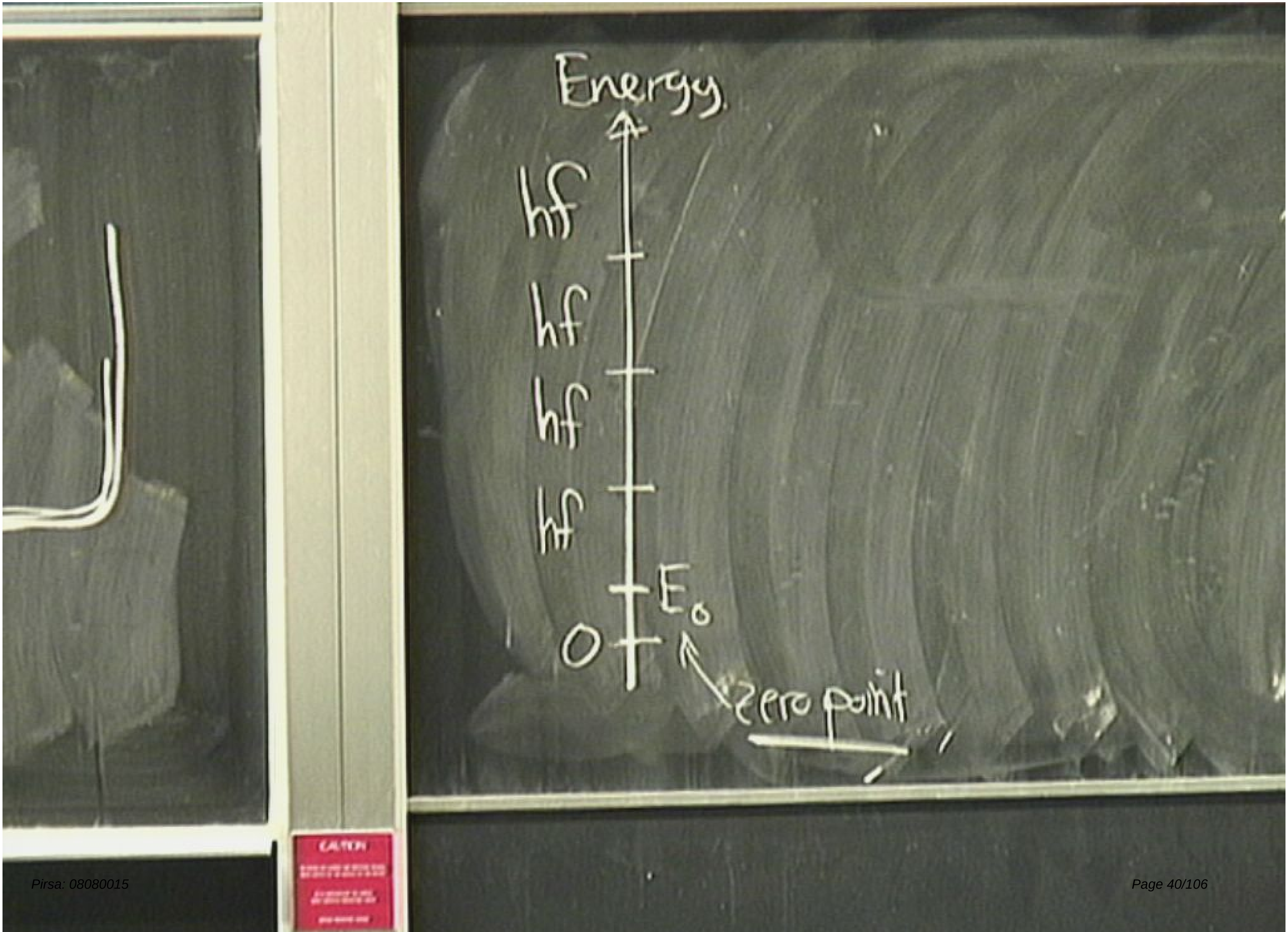

qualitatively similar to

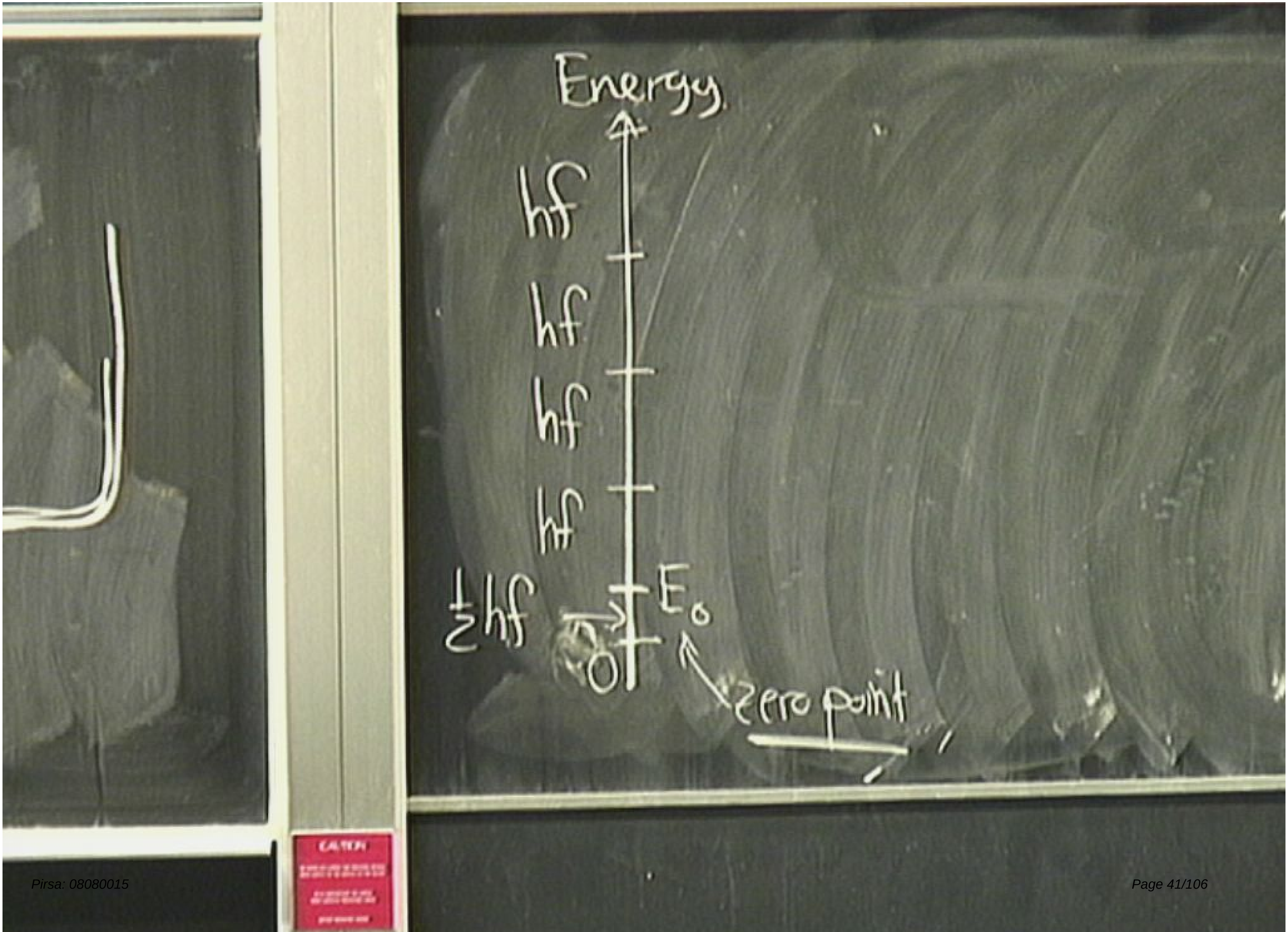

qualitatively similar to

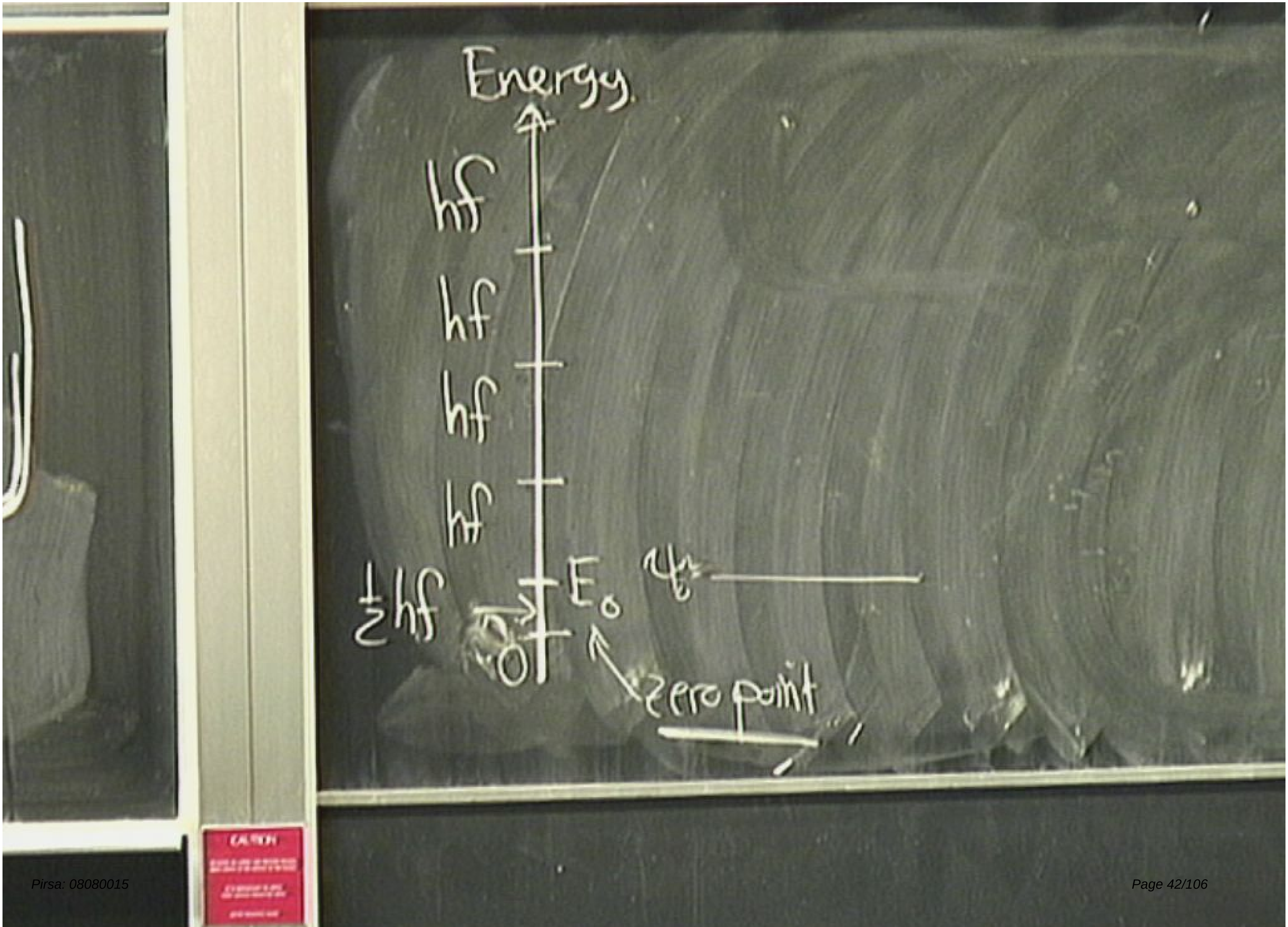

Energy
0

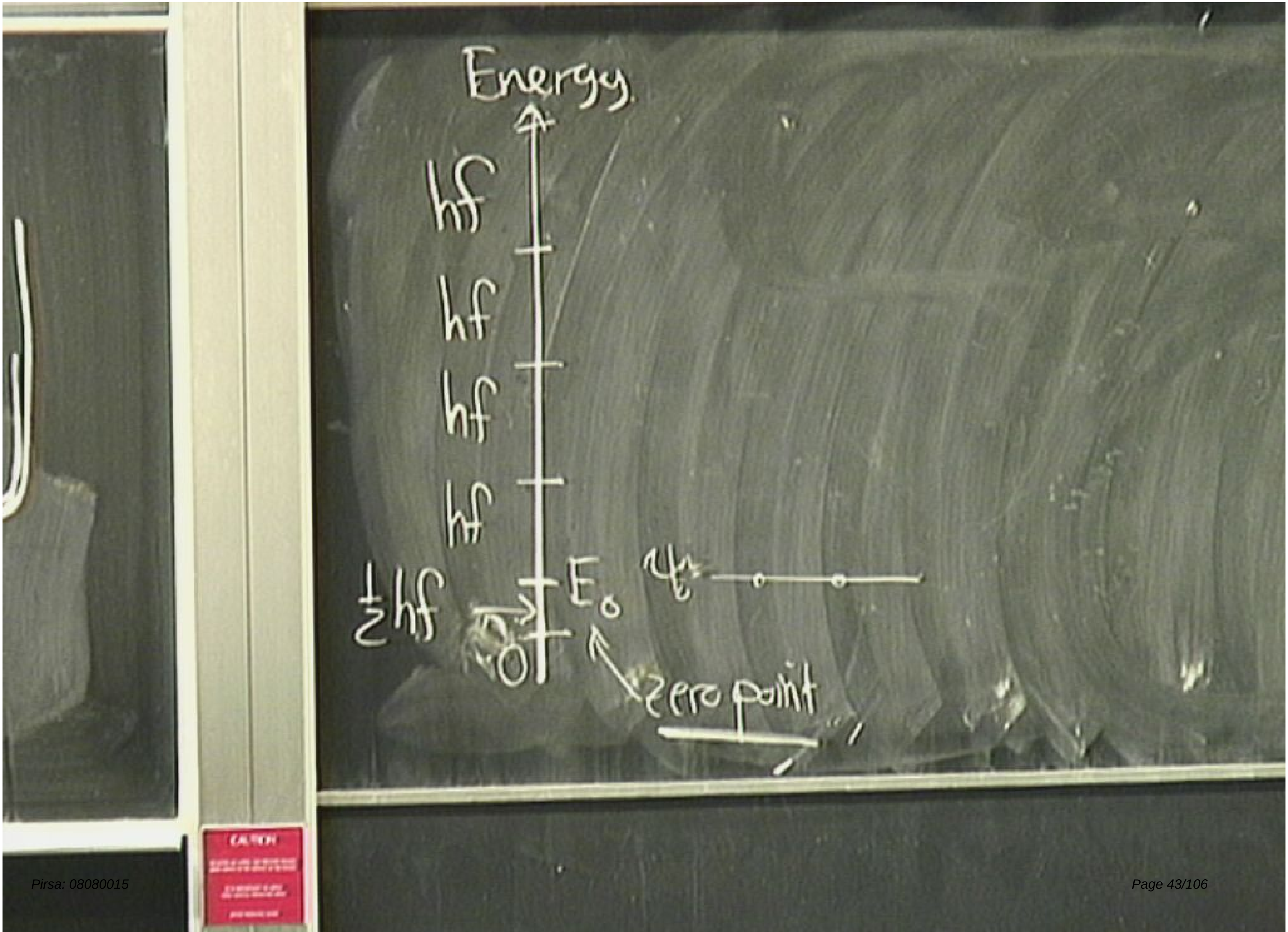

qualitatively similar to
Δx = 0
Δp = 0

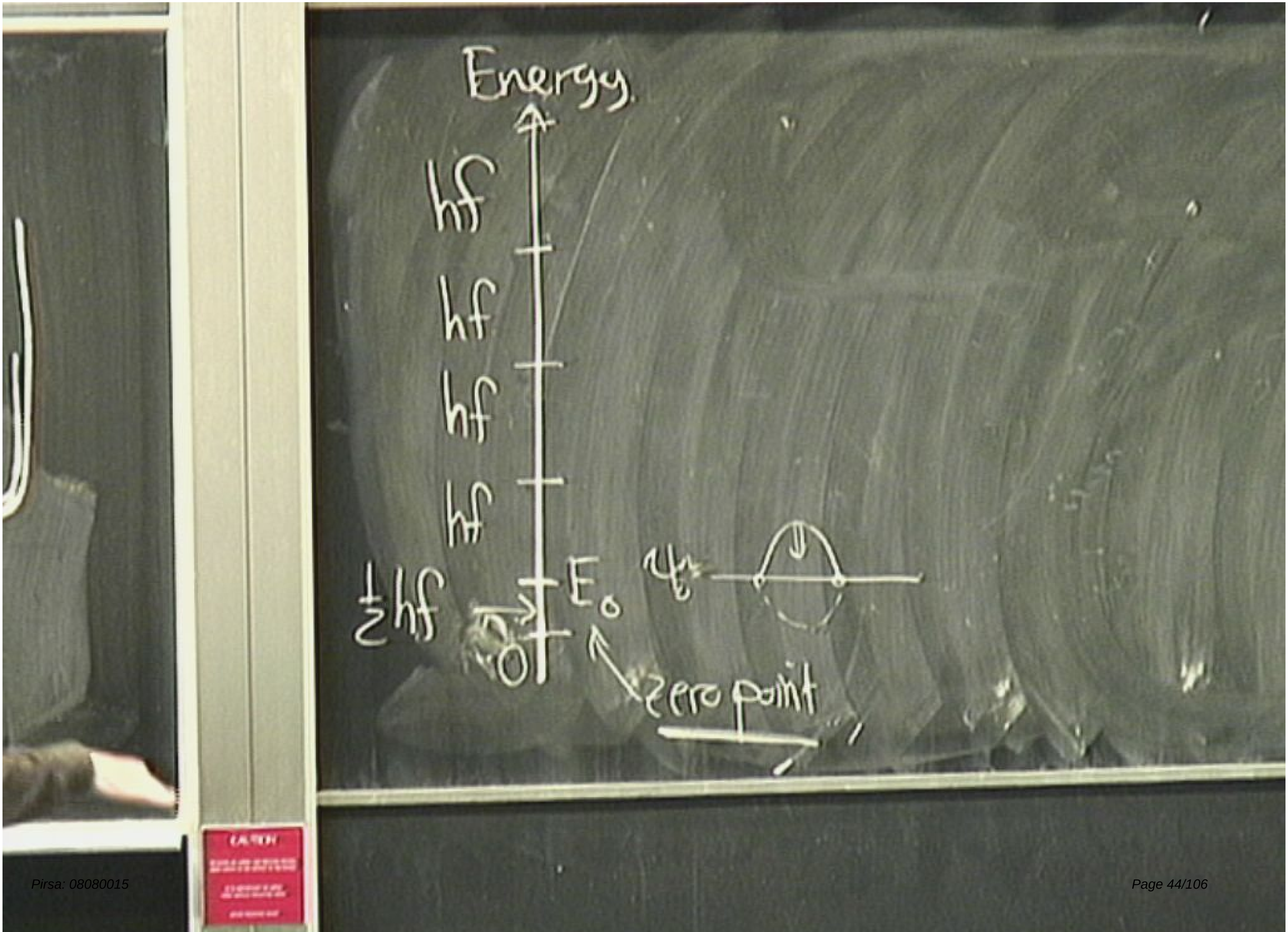

Energy
E_0
0
zero point

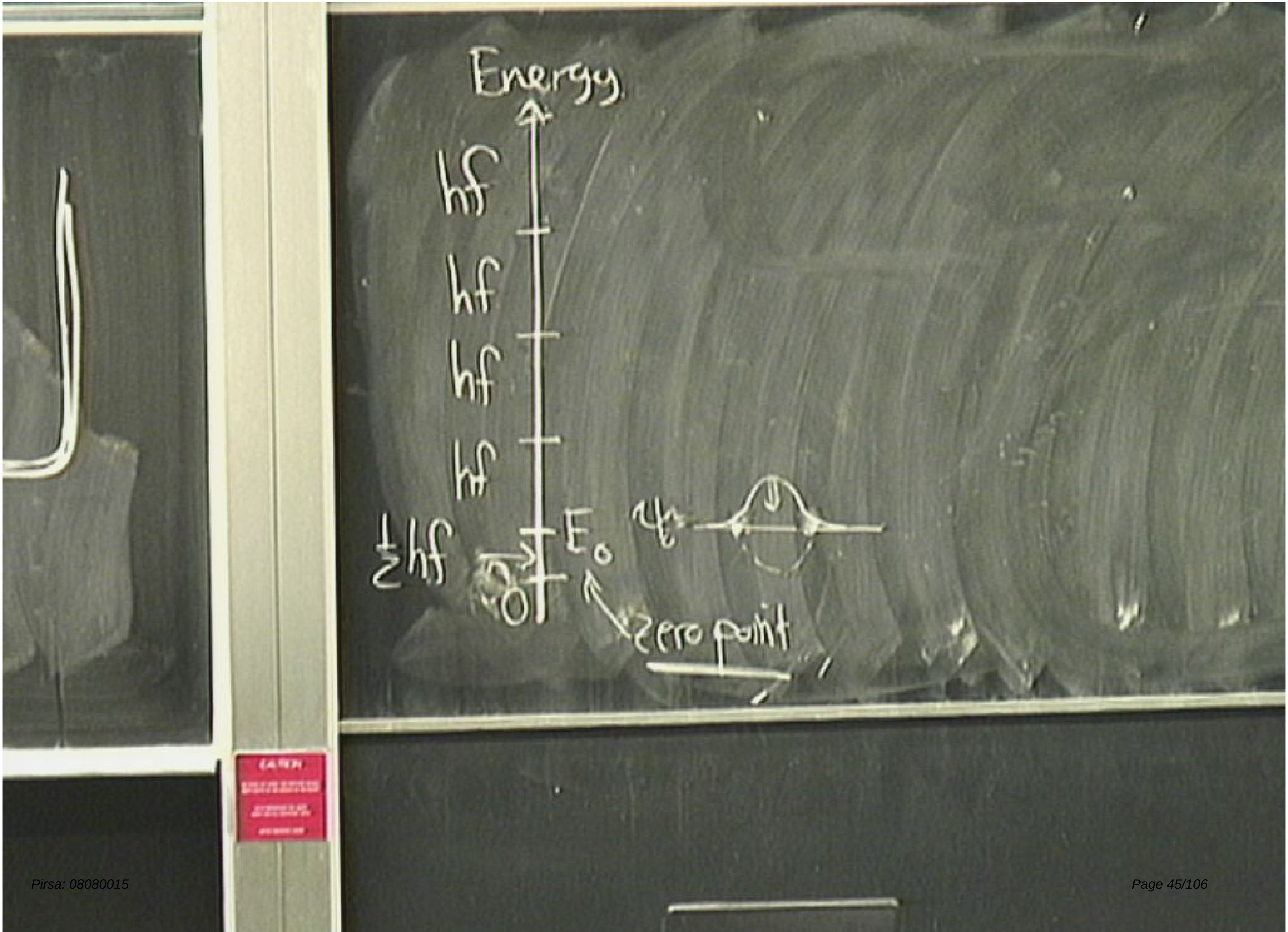

Energy
hf
hf
hf
hf
E0
0
zero point


Energy
hf
hf
hf
hf
½hf
E0
0
zero point

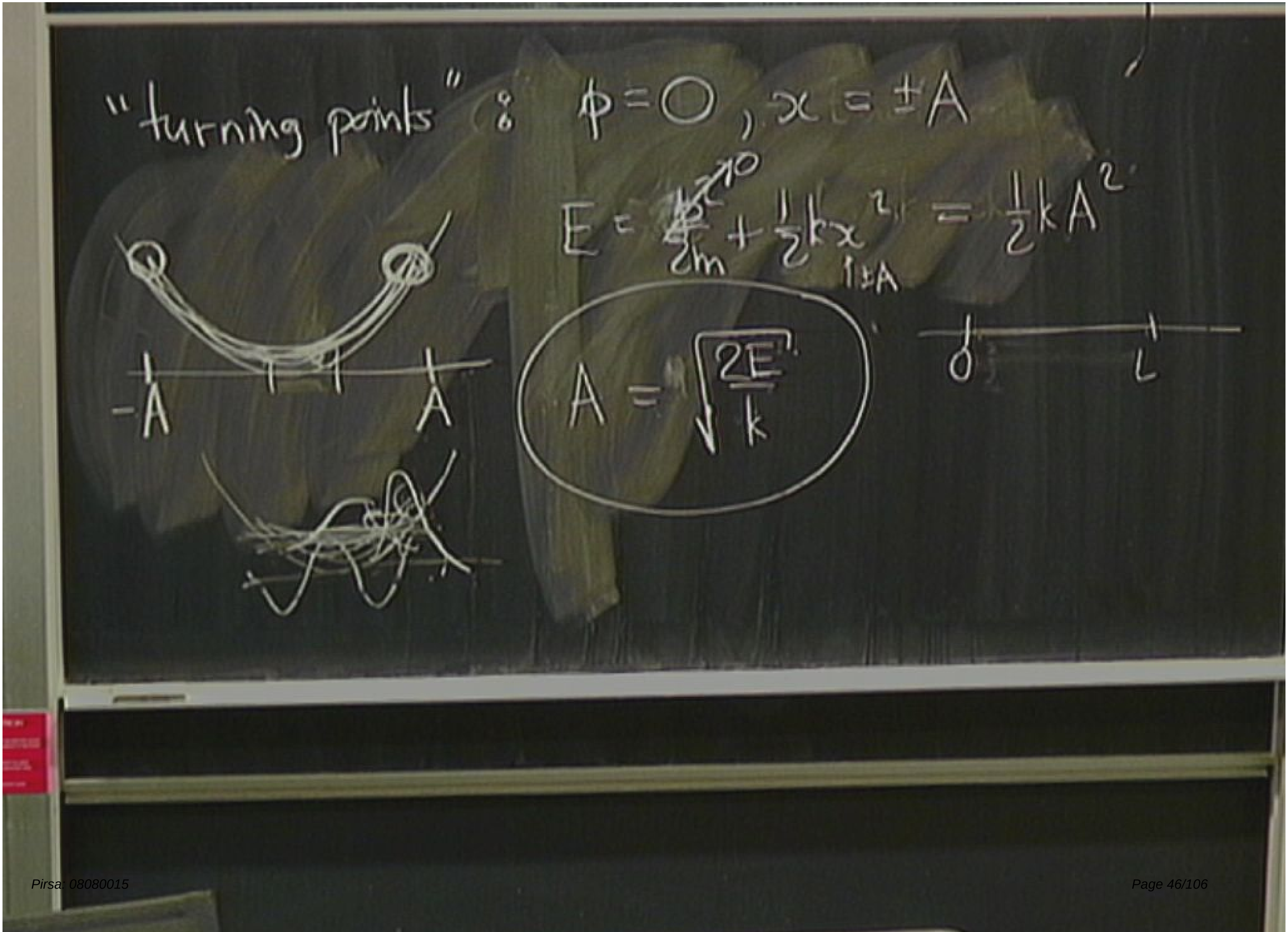

Energy
hf
hf
hf
hf
E0
1/2 hf
0
zero point

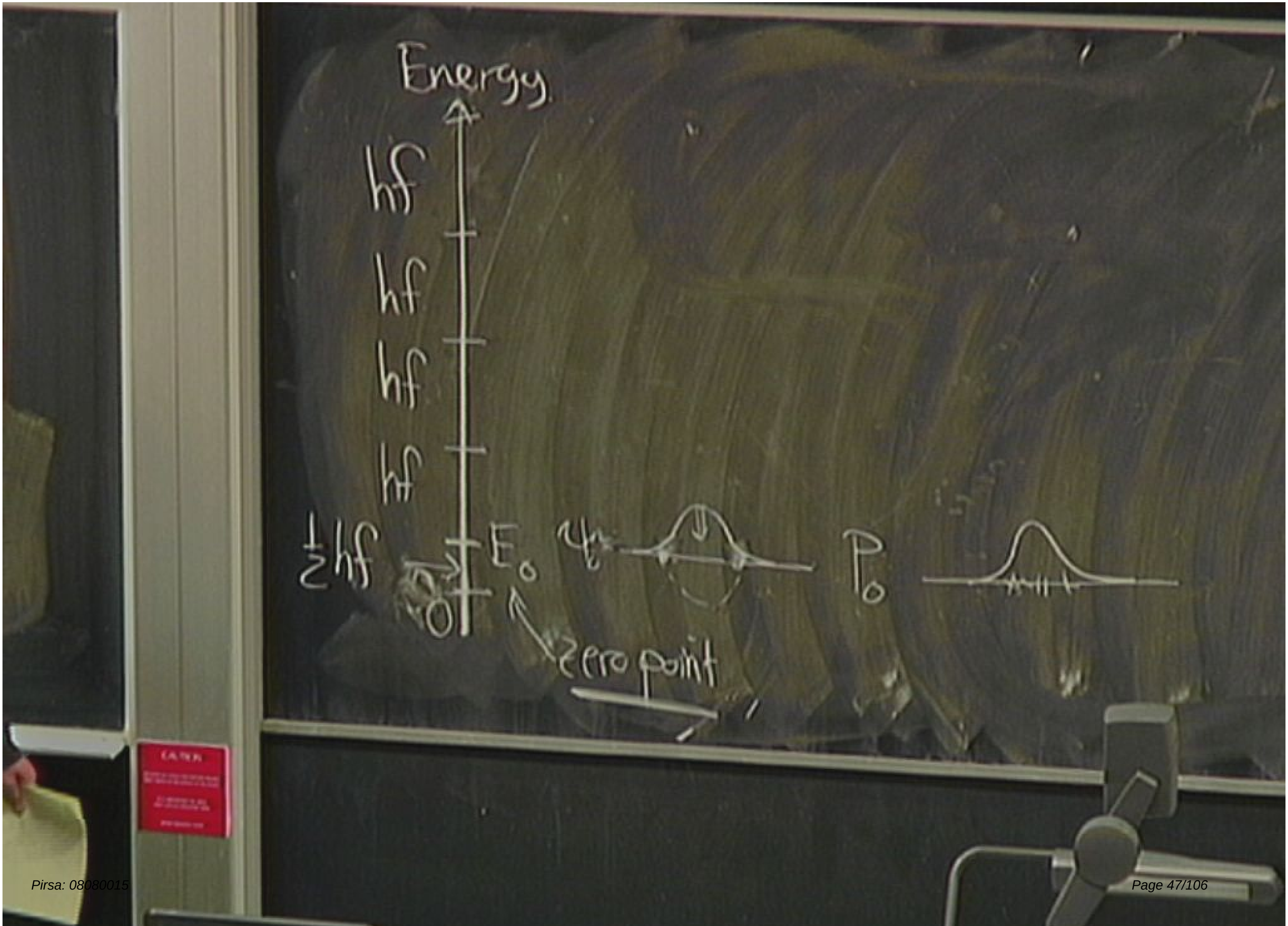

Energy
hf
hf
hf
hf
½ hf
E₀
0
zero point
CAUTION

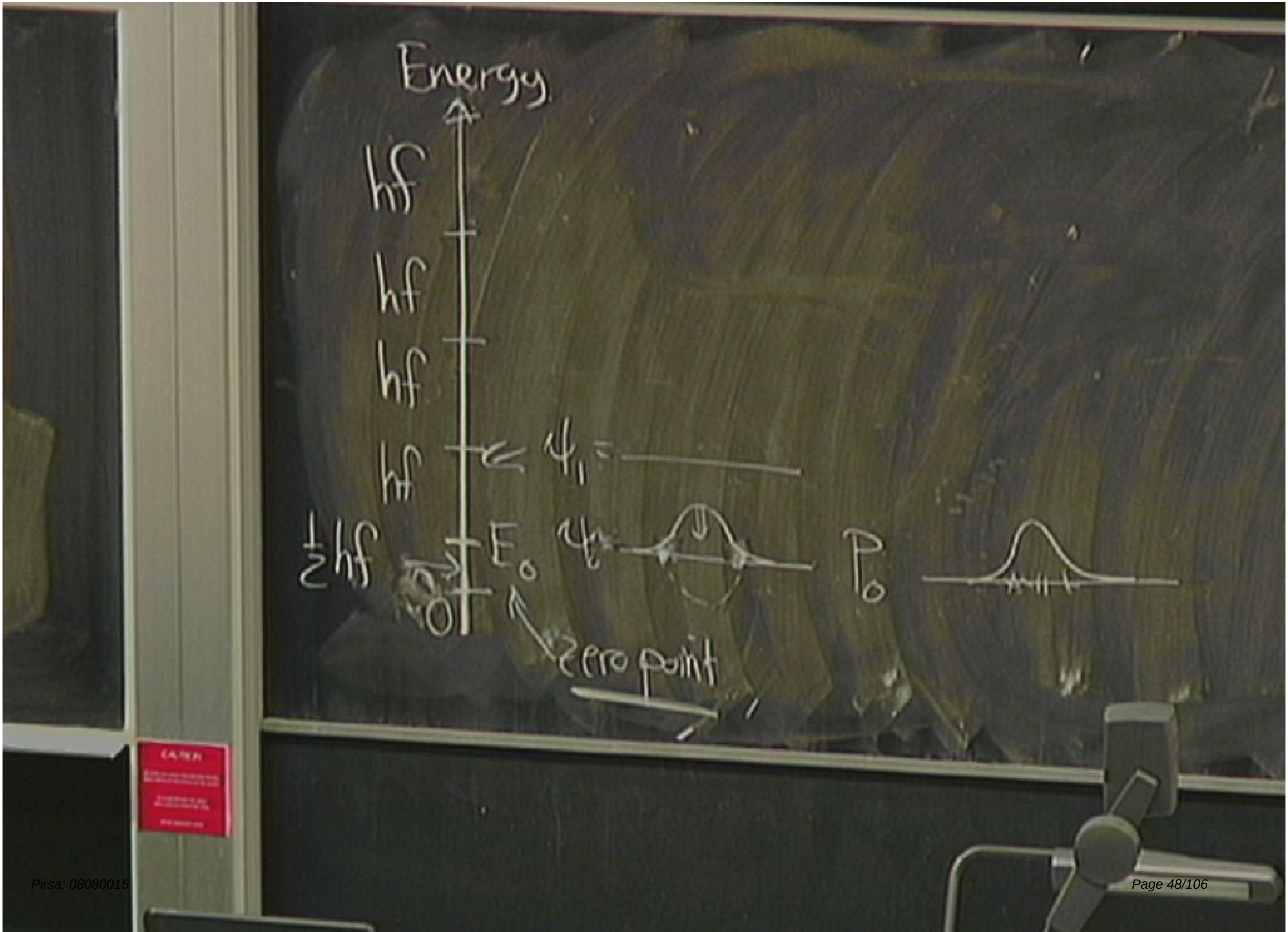

Energy
hf
hf
hf
hf
½hf
E₀
0
ψ
zero point

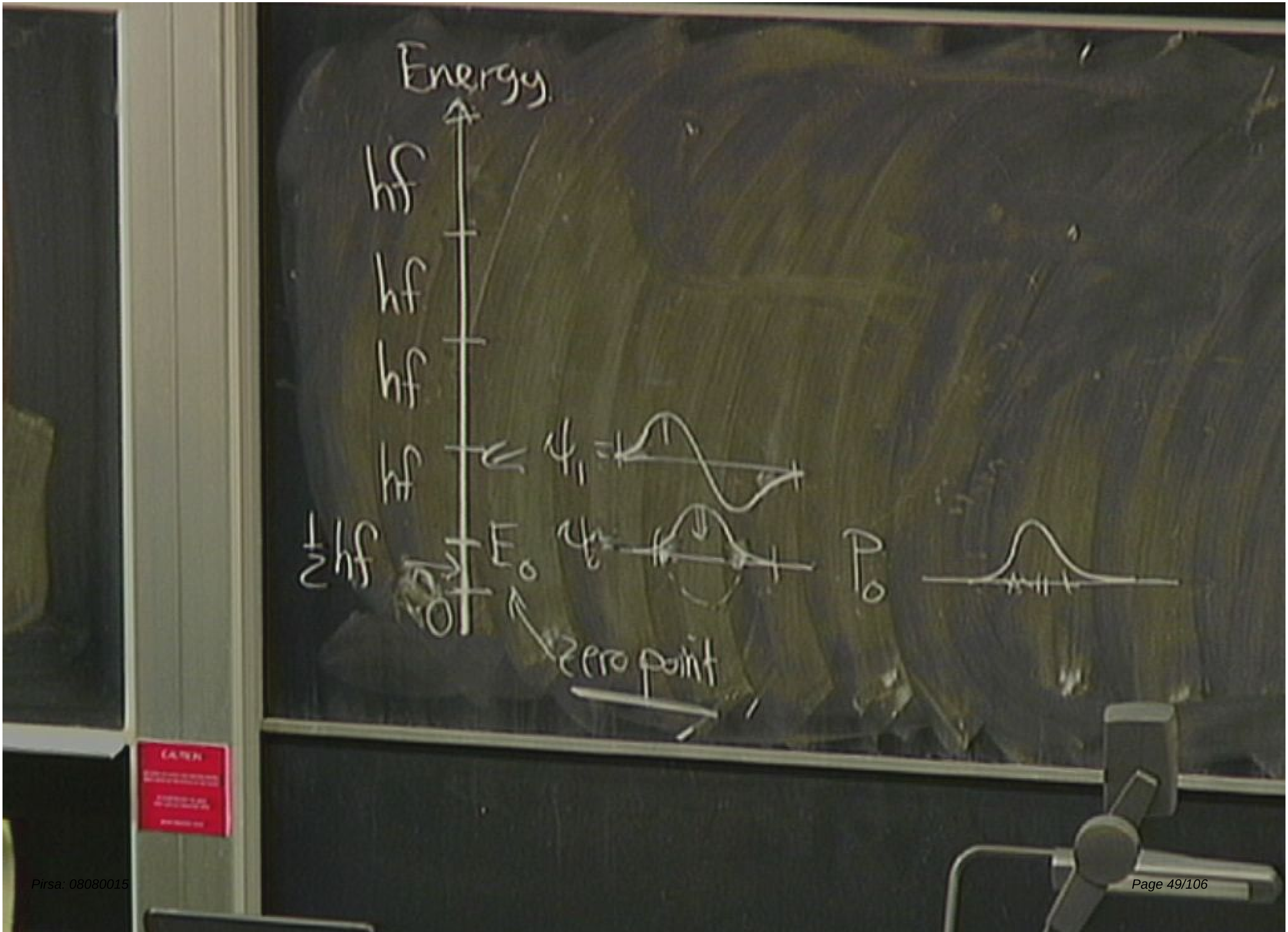


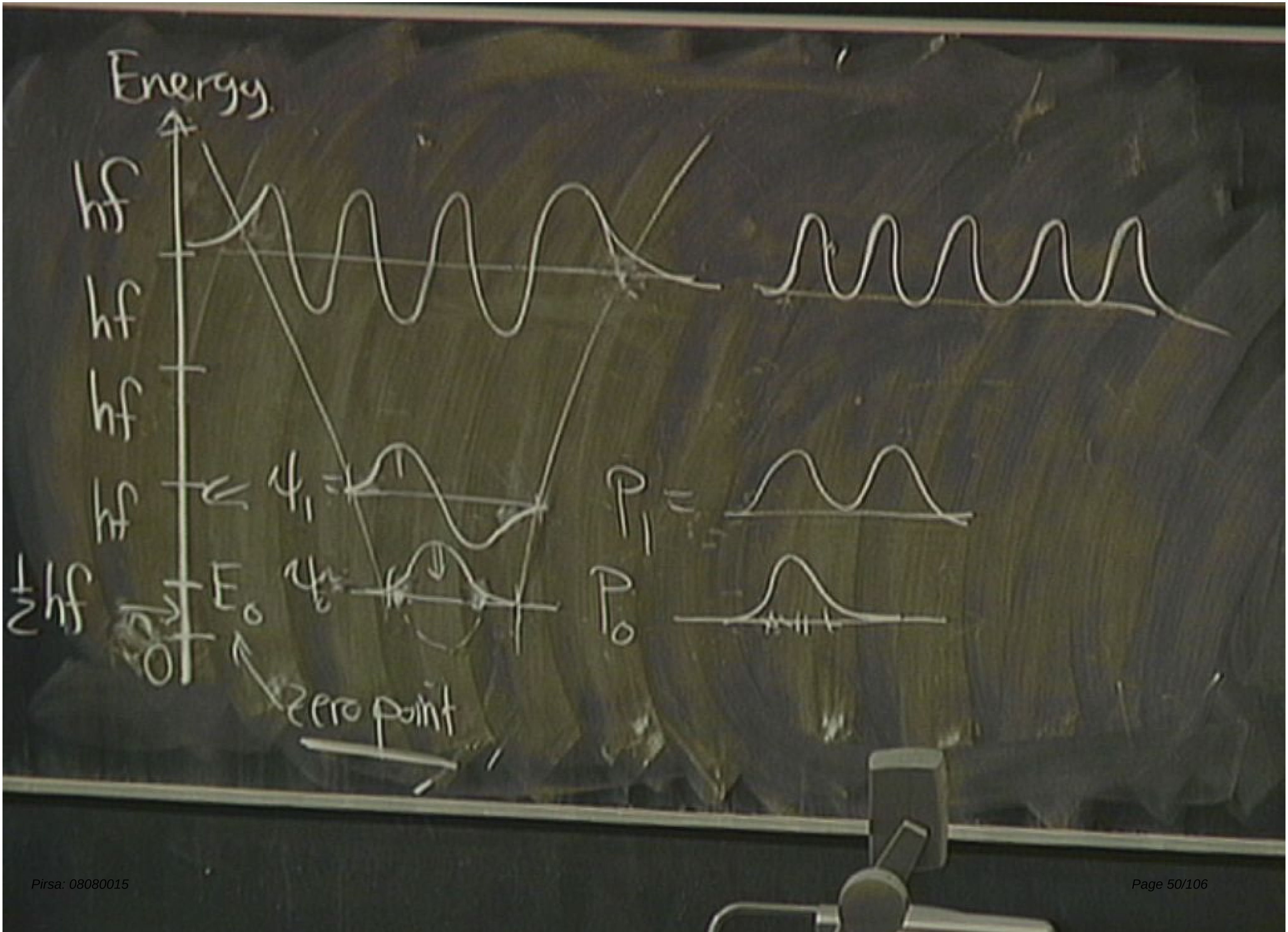
Energy
hf
hf
hf
hf
$\frac{1}{2}hf$
E_0
ψ
0
zero point

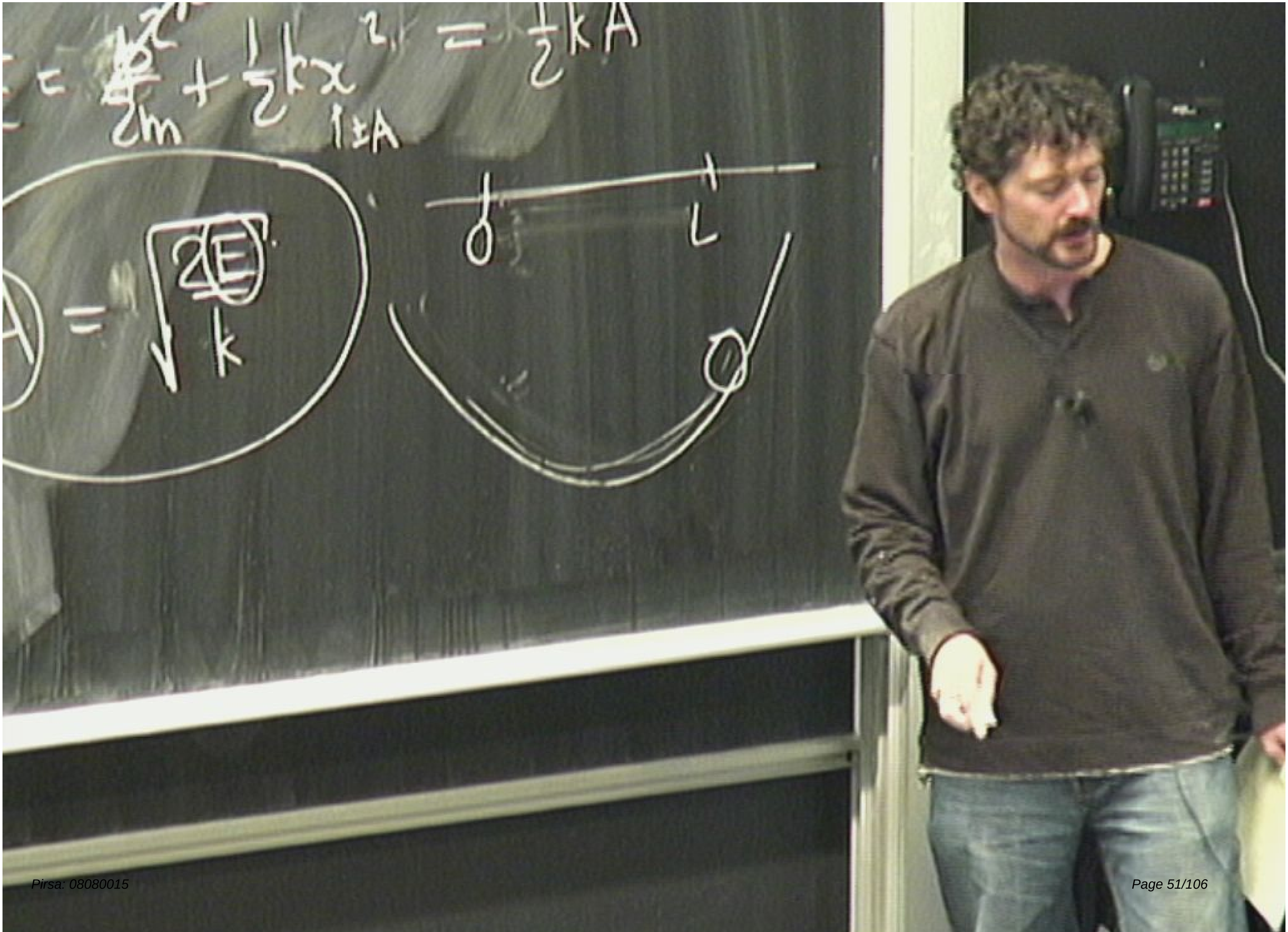

"turning points": p = 0, x = ±A
E = p²/2m + ½kx² = ½kA²
±A
A = √(2E/k)
0
L
-A
A

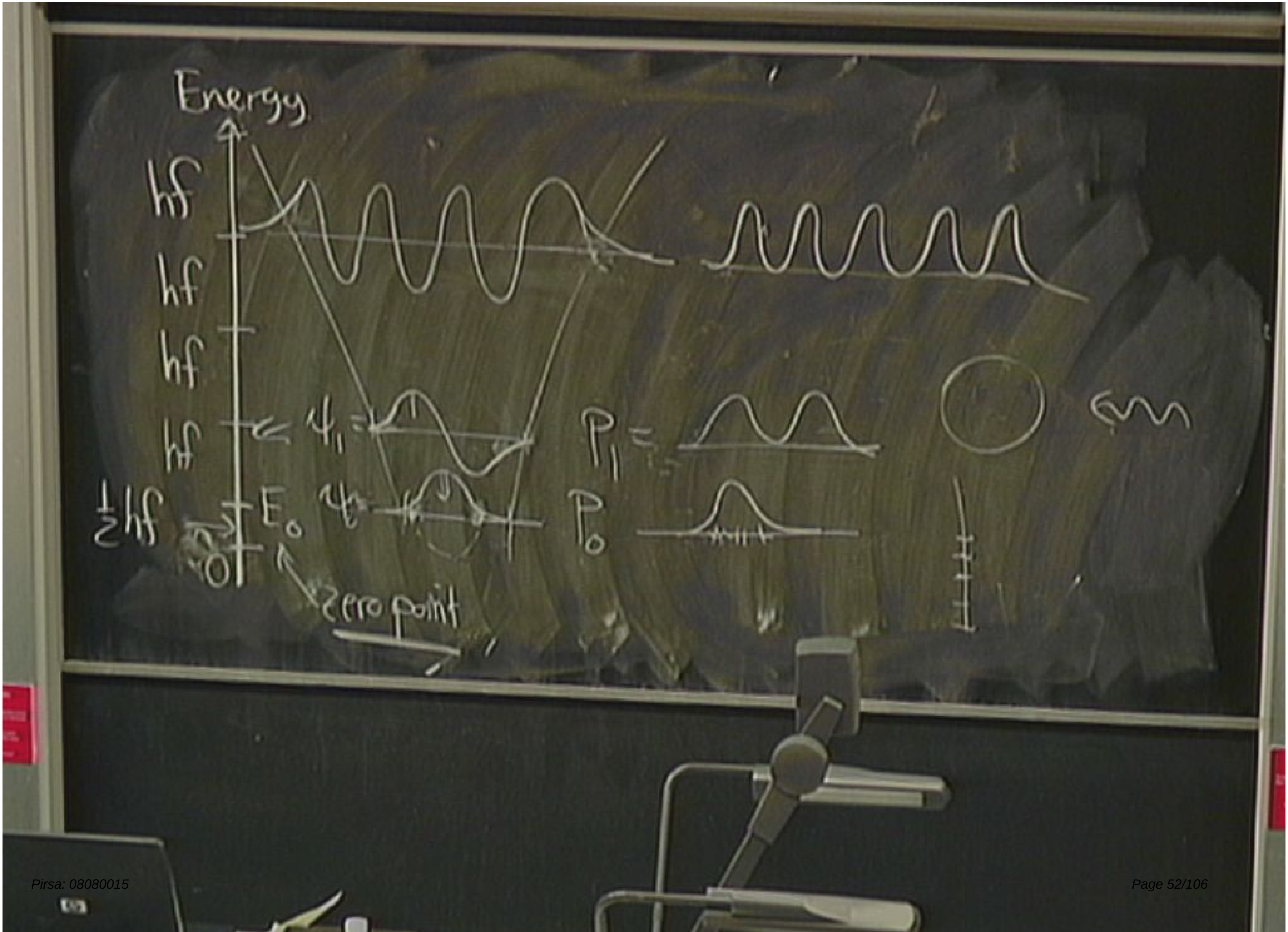

Energy
hf
hf
hf
hf
½hf
0
E₀
ψ₀
P₀
zero point

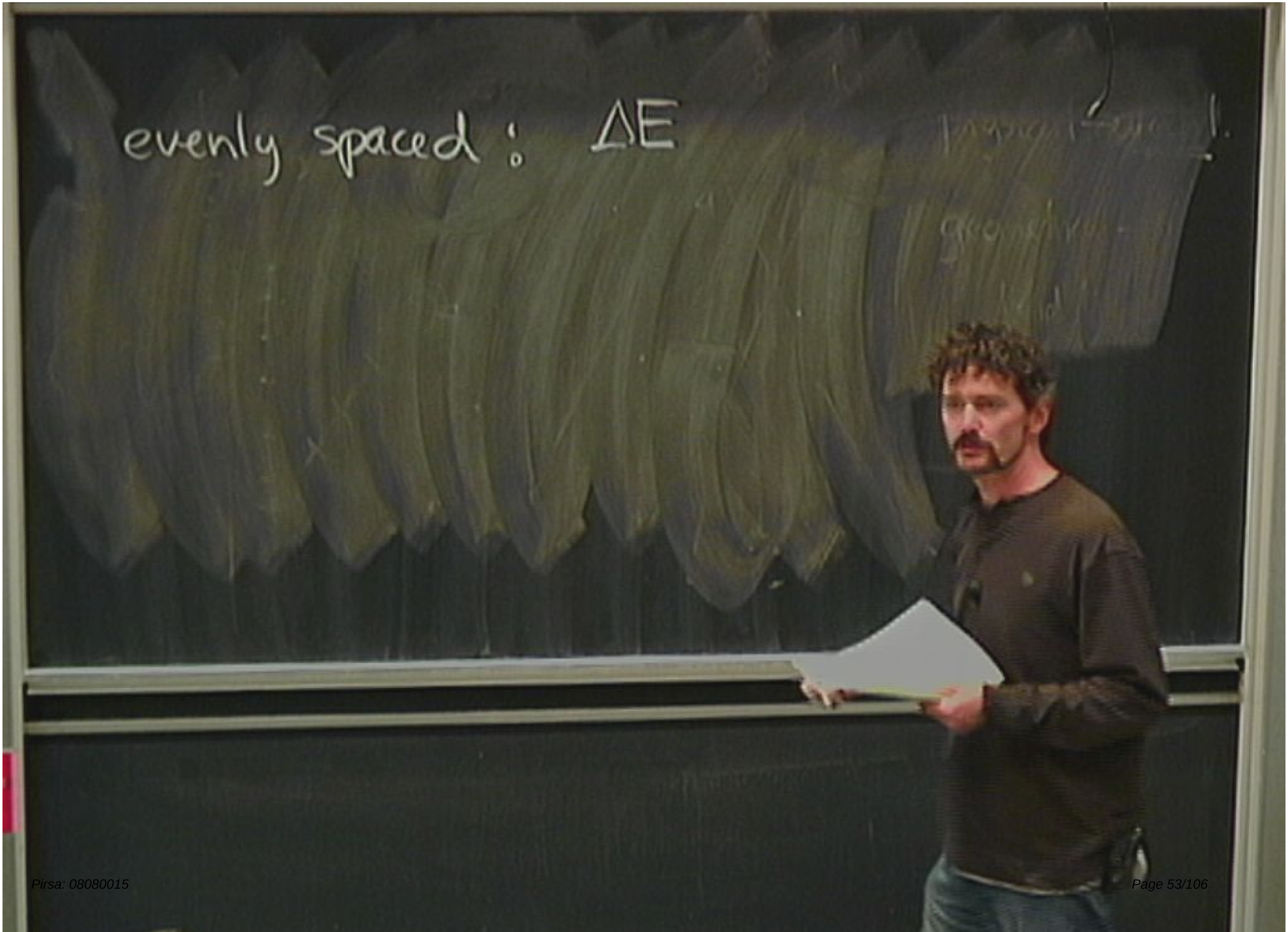

Energy
hf
hf
hf
hf
½hf
0
E₀
ψ₁ =
ψ₀
P₀
zero point

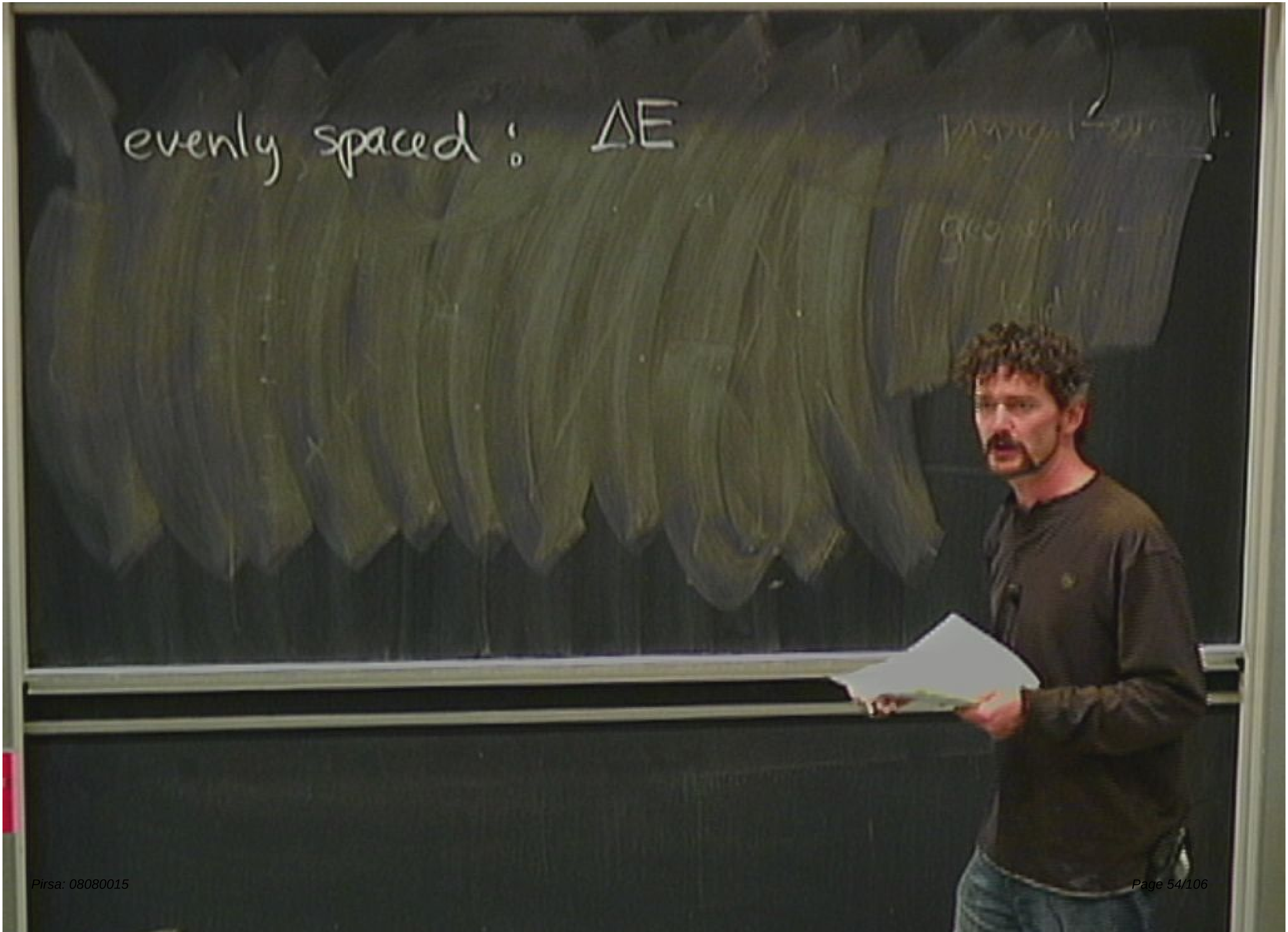

Energy
hf
hf
hf
hf
½hf
E₀
ψ₁ =
ψ₀ =
P₀
0
zero point

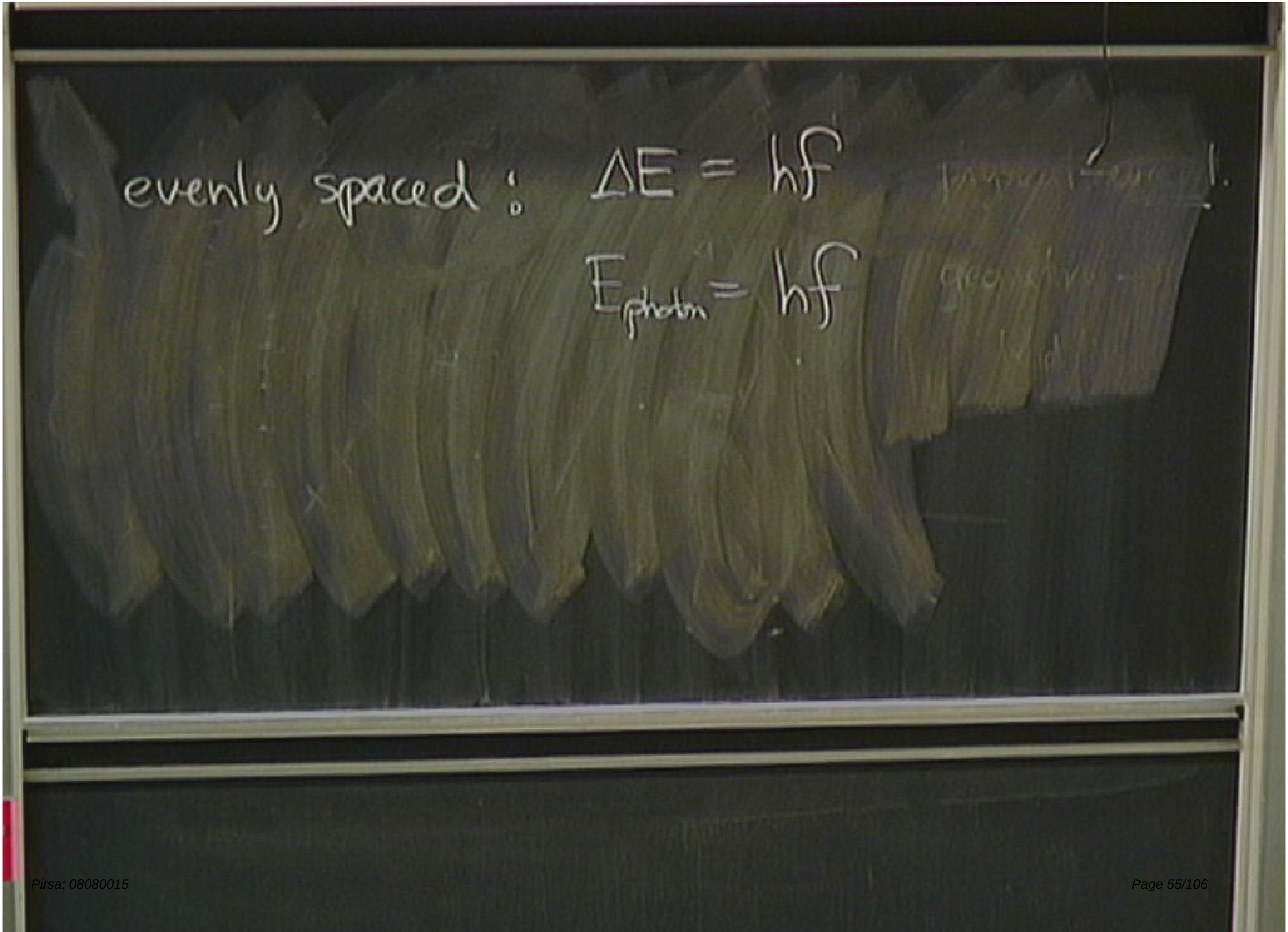

Energy
hf
hf
hf
hf
½hf
0
E₀
ψ₁ =
ψ₀
P₁ =
P₀
zero point

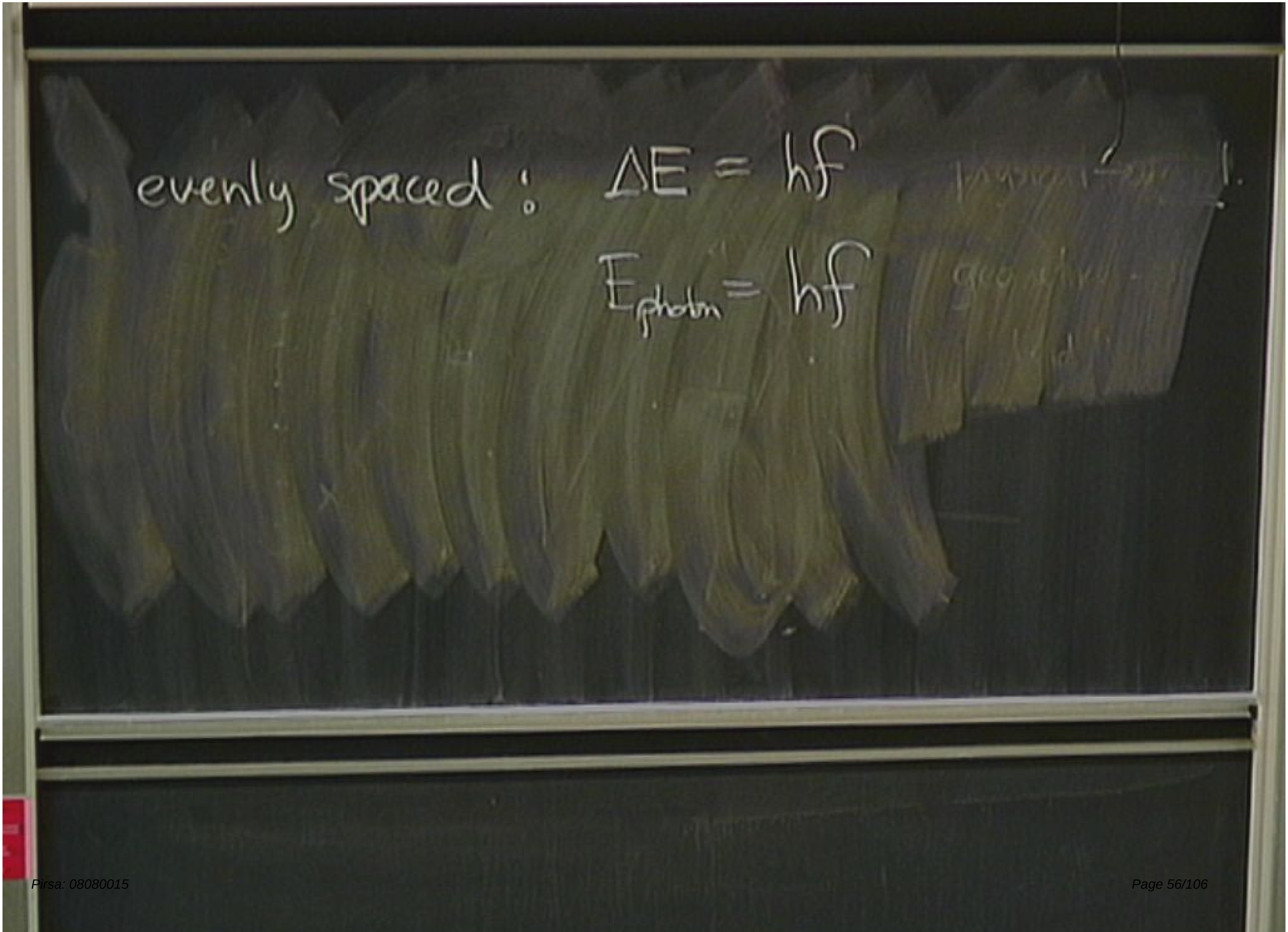

A = √(2E/k)
L

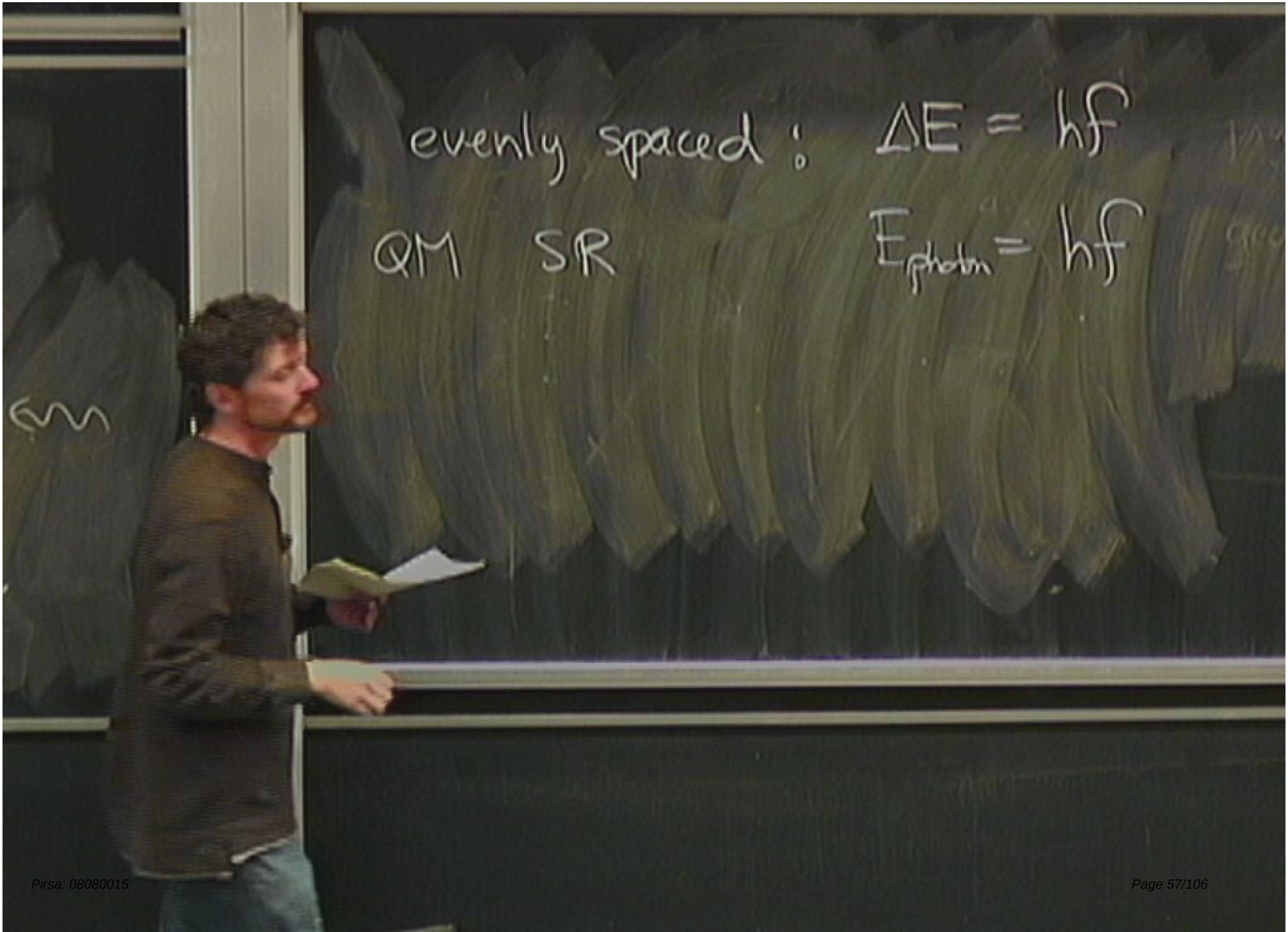

Energy
hf
hf
hf
hf
1/2 hf
0
E0
zero point

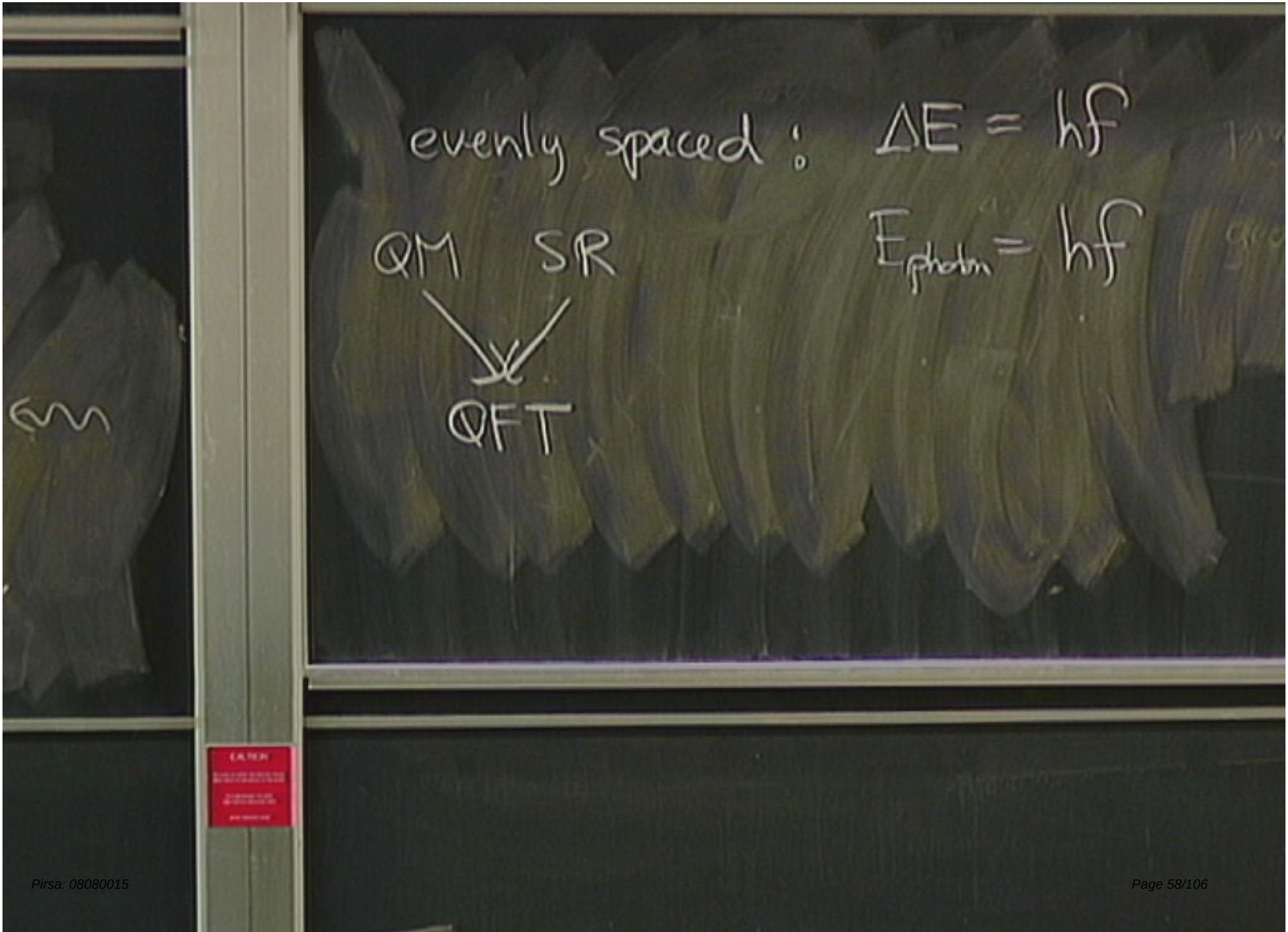

evenly spaced : ΔE


evenly spaced: ΔE


evenly spaced: $\Delta E = hf$
$E_{photon} = hf$


evenly spaced: $\Delta E = hf$
$E_{photon} = hf$

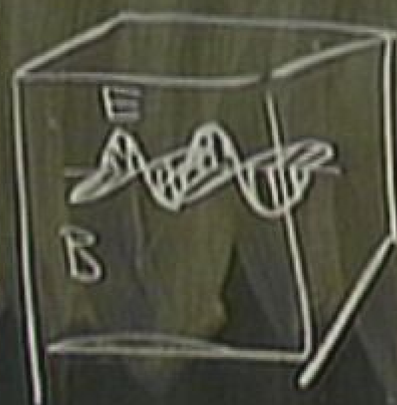

evenly spaced: ΔE = hf
QM SR
E photon = hf

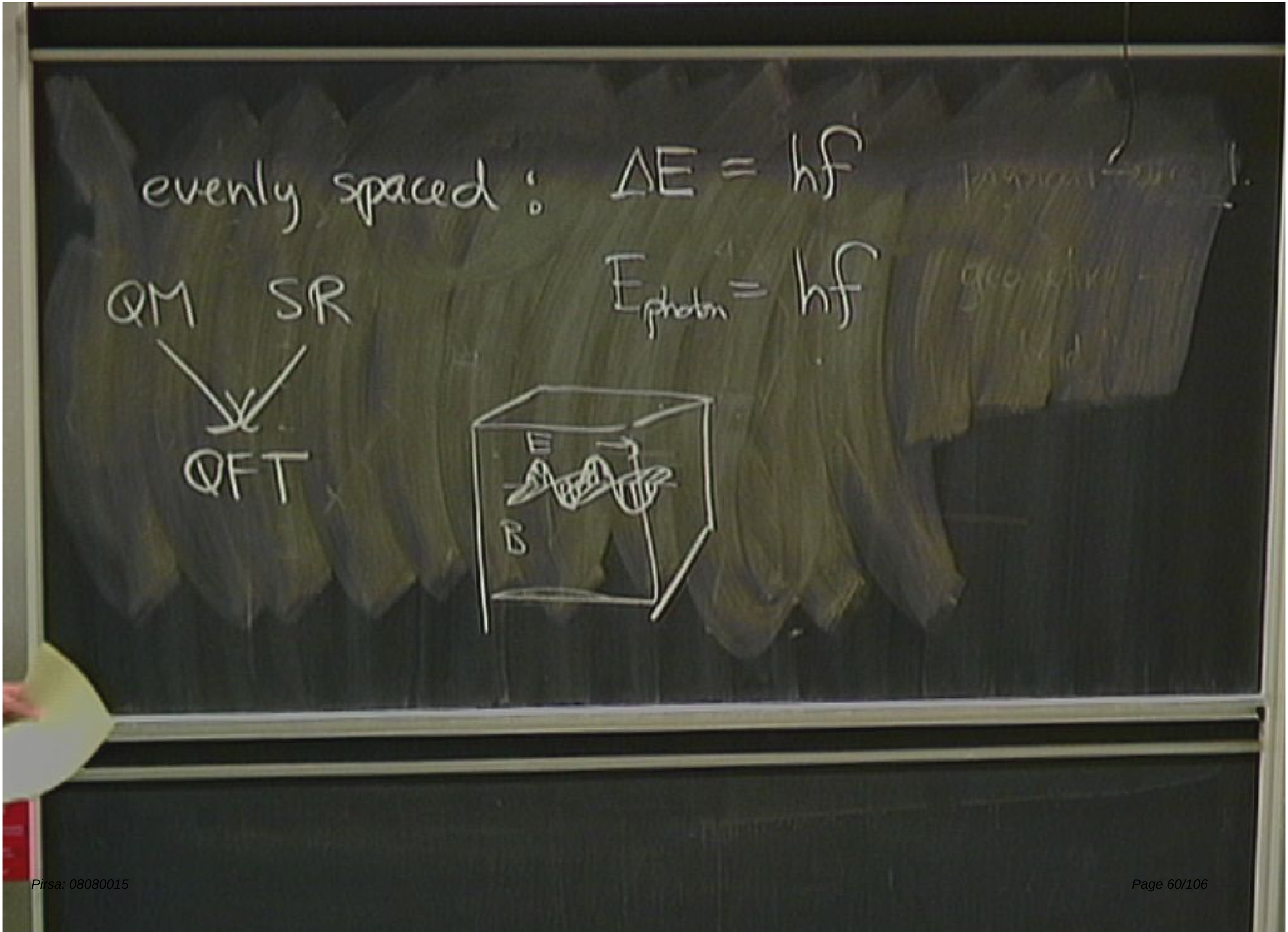

evenly spaced: ΔE = hf
QM SR
QFT
E photon = hf

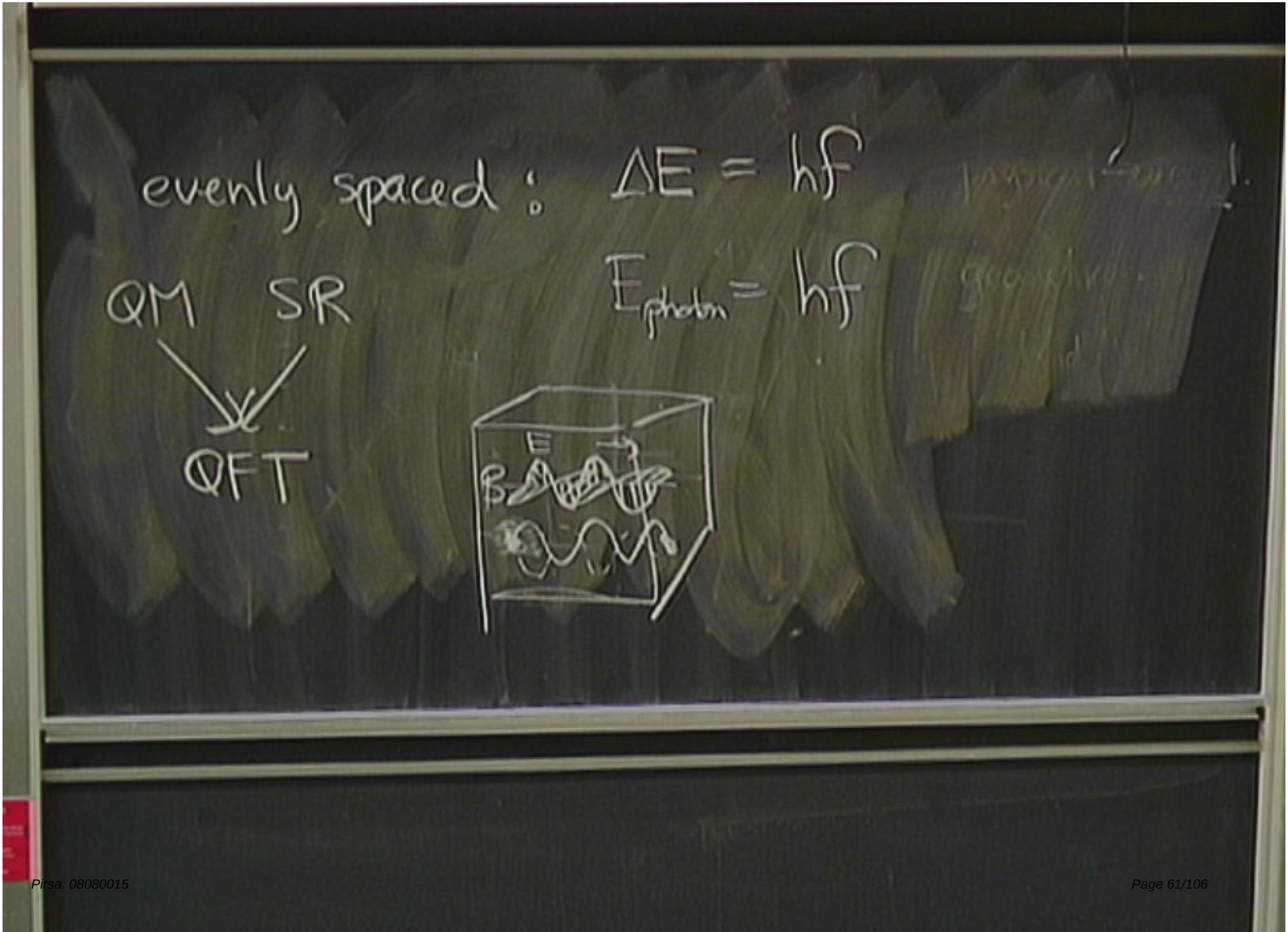
evenly spaced : $\Delta E = hf$

QM SR → QFT

$E_{photon} = hf$




evenly spaced: ΔE = hf
E photon = hf
QM SR
QFT
E
B


evenly spaced: ΔE = hf
E photon = hf
QM SR
QFT
E
B

evenly spaced: $\Delta E = hf$

$E_{photon} = hf$

QM SR

↘ ↙

QFT

each e/m standing wave (mode) of freq f

evenly spaced: $\Delta E = hf$

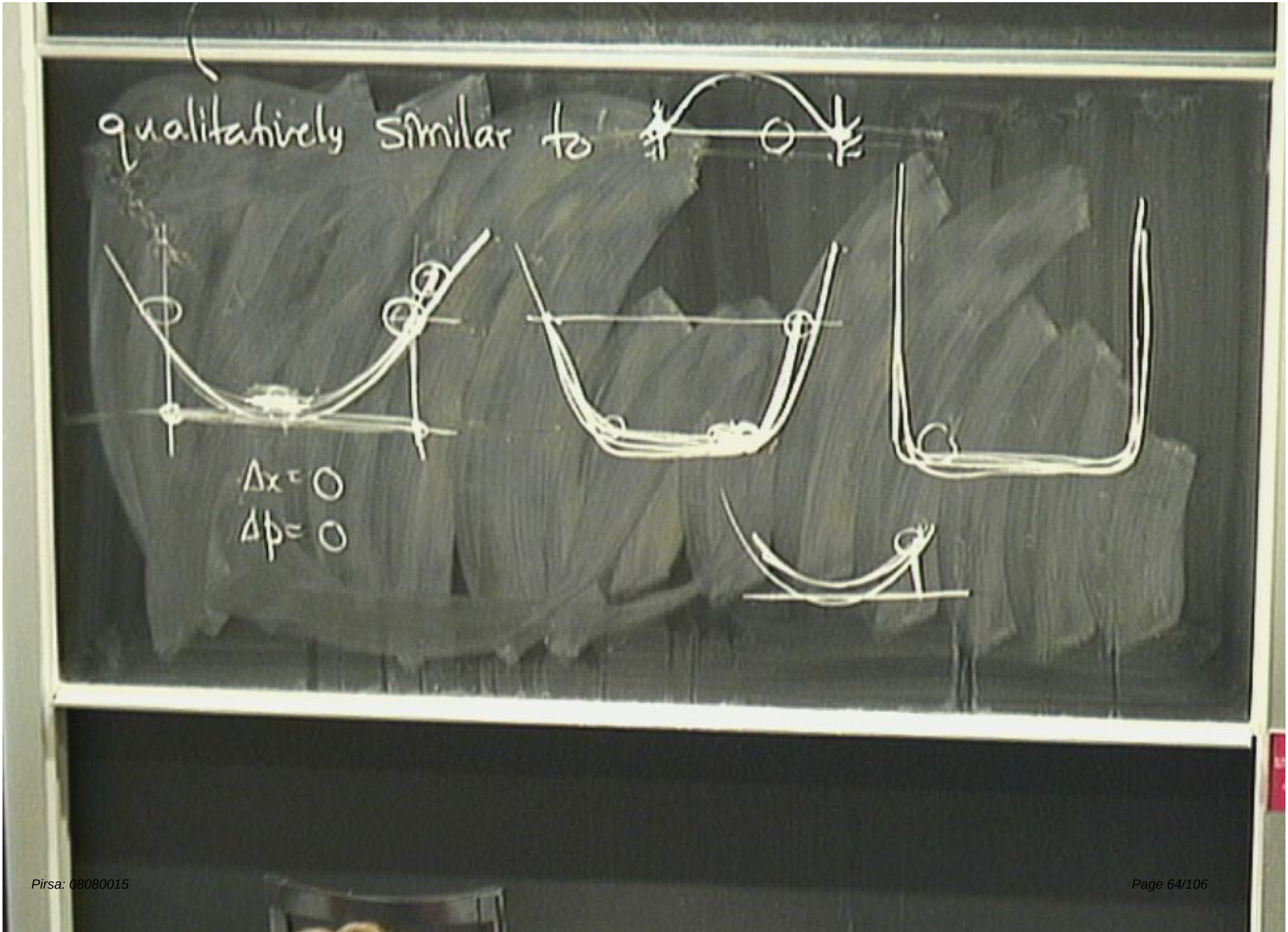
$E_{photon} = hf$

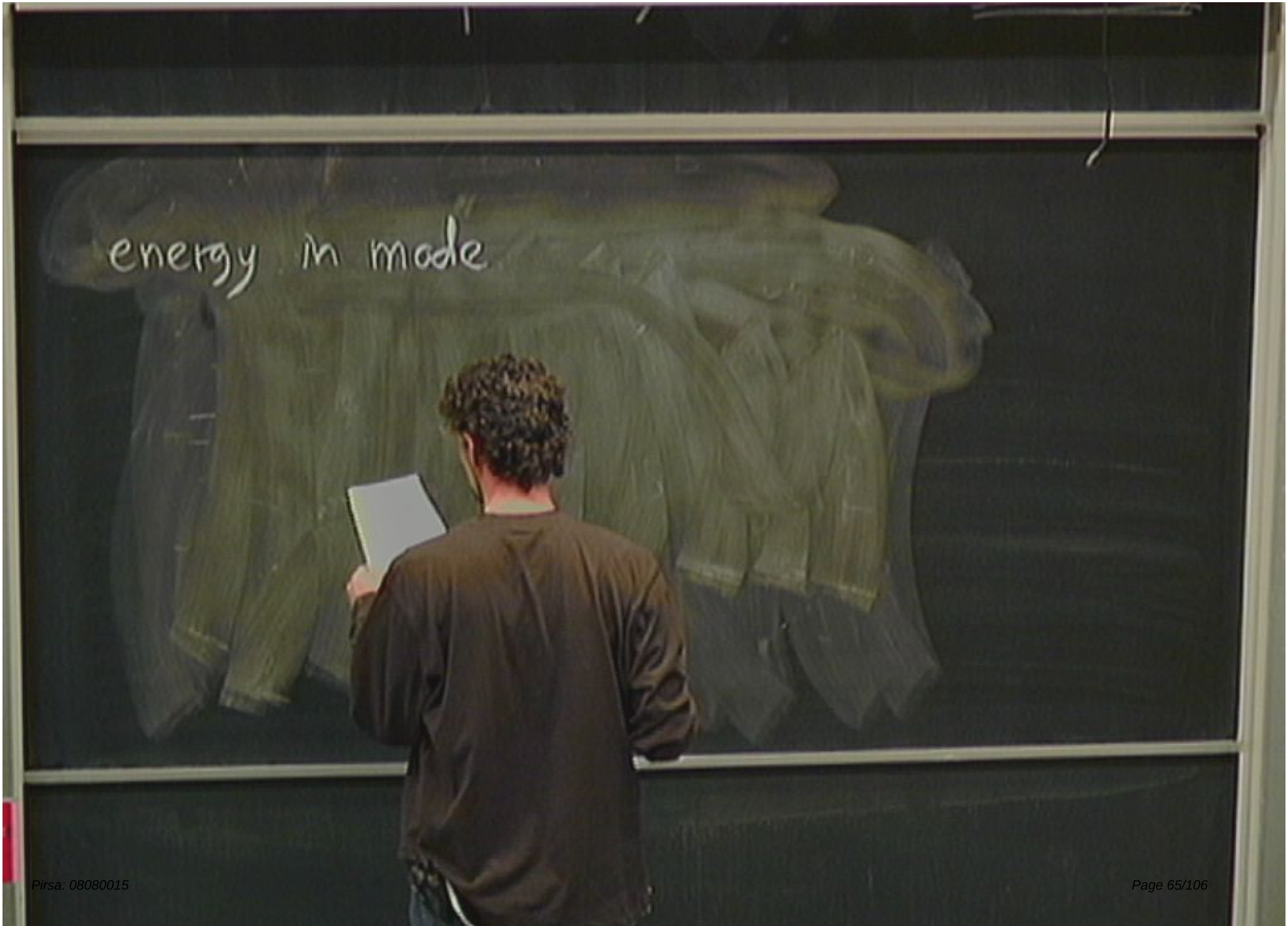
QM SR

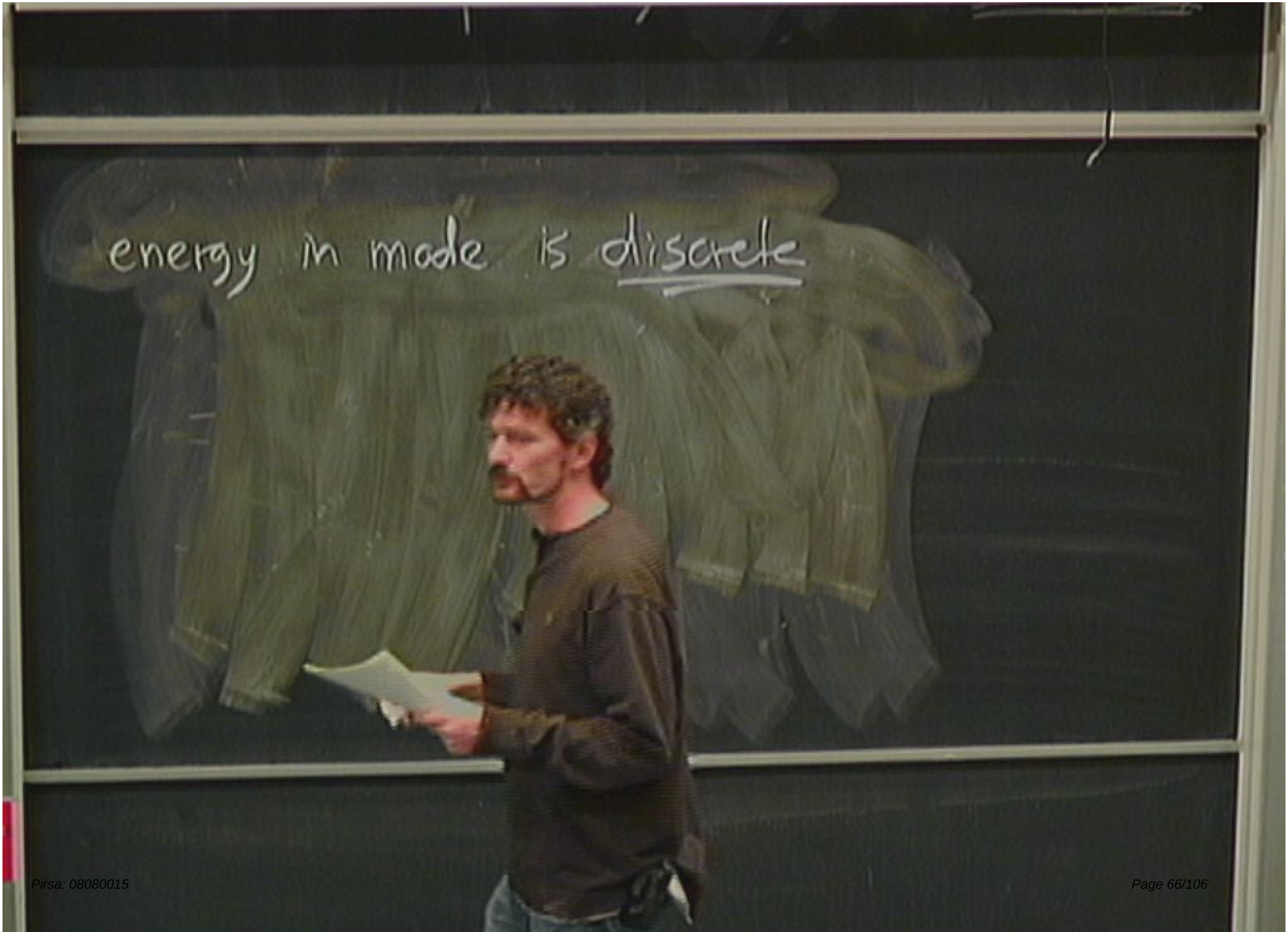
↘ ↙

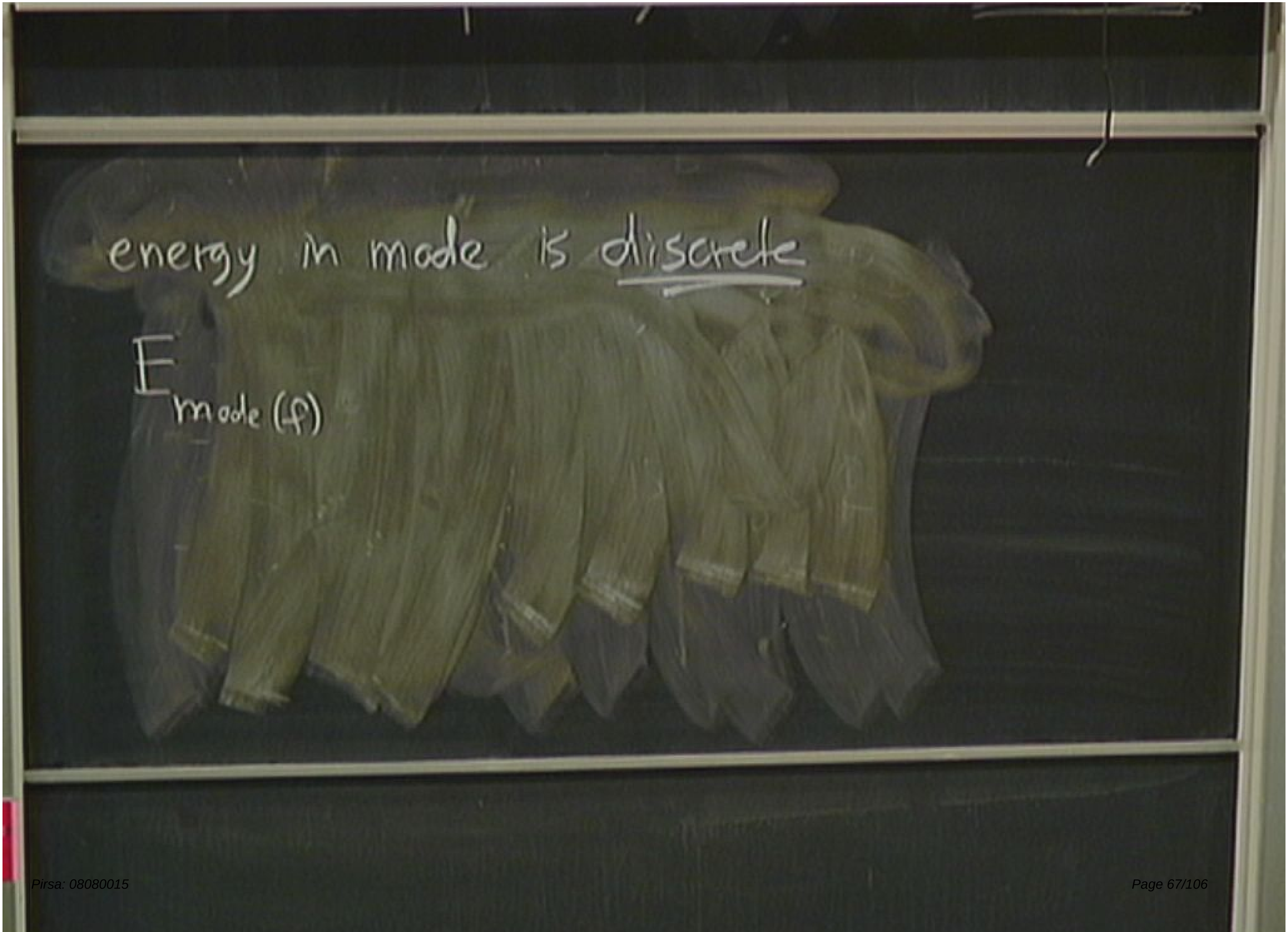
QFT

each e/m standing wave (mode) of freq f oscillates harmonically


qualitatively similar to
Δx = 0
Δp = 0

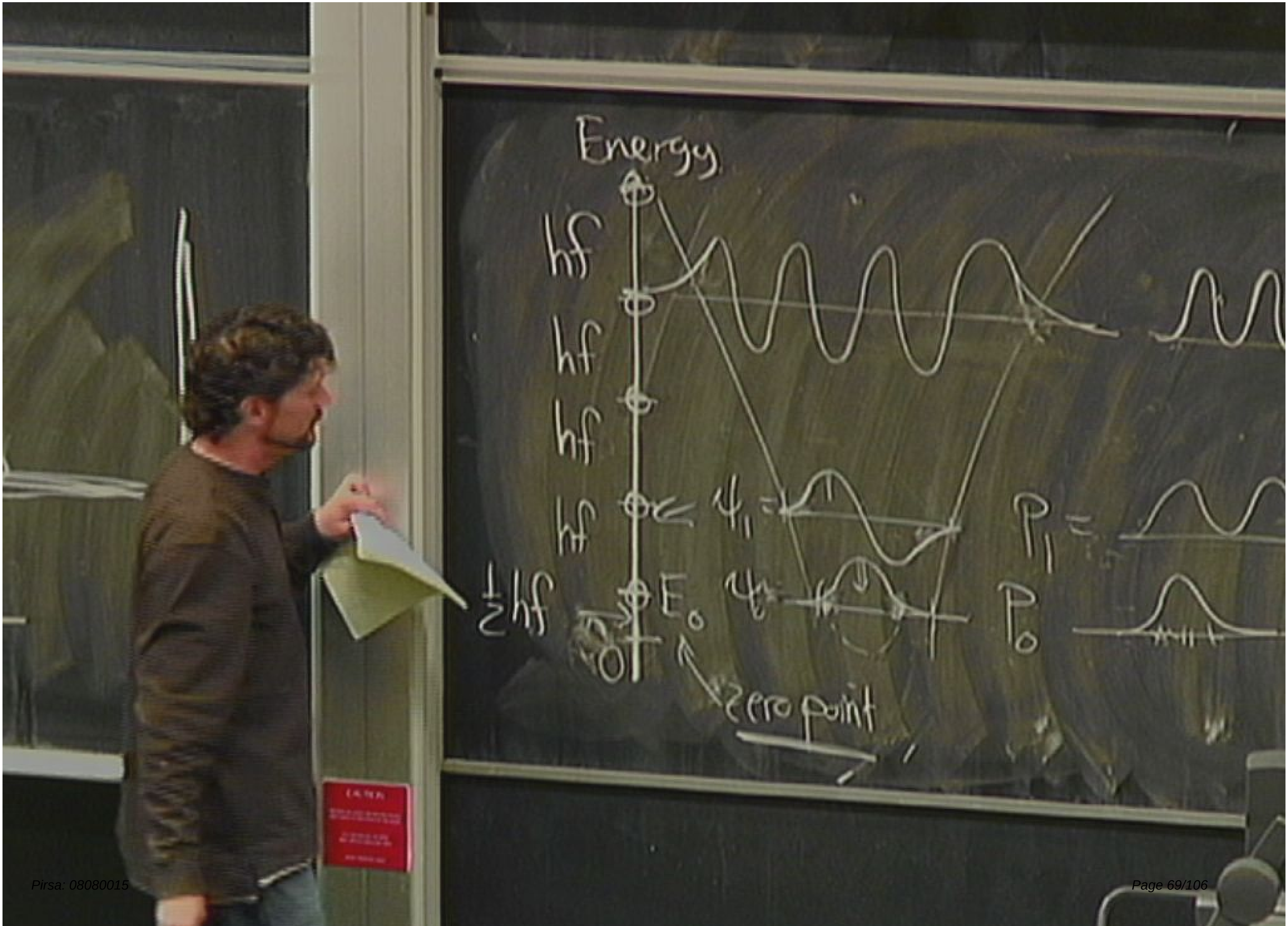

energy in mode


energy in mode is discrete


energy in mode is discrete
$E_{mode(f)}$

energy in mode is <u>discrete</u>

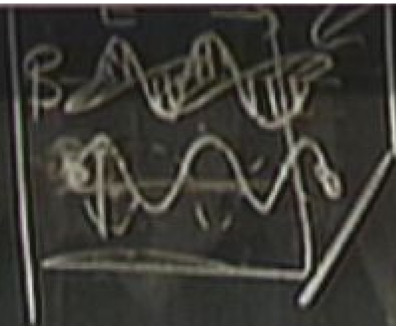
$$E_{mode(f)} = nhf + \frac{1}{2}hf$$


Energy
hf
hf
hf
hf
½hf
E₀
ψ₁ =
ψ₀ =
P₁ =
P₀
0
zero point

energy in mode is discrete

$$E_{mode(f)} = nhf + \frac{1}{2}hf \quad , n = 0, 1, 2, 3, \ldots$$

QFT



(mode) of freq f
oscillates harmonically

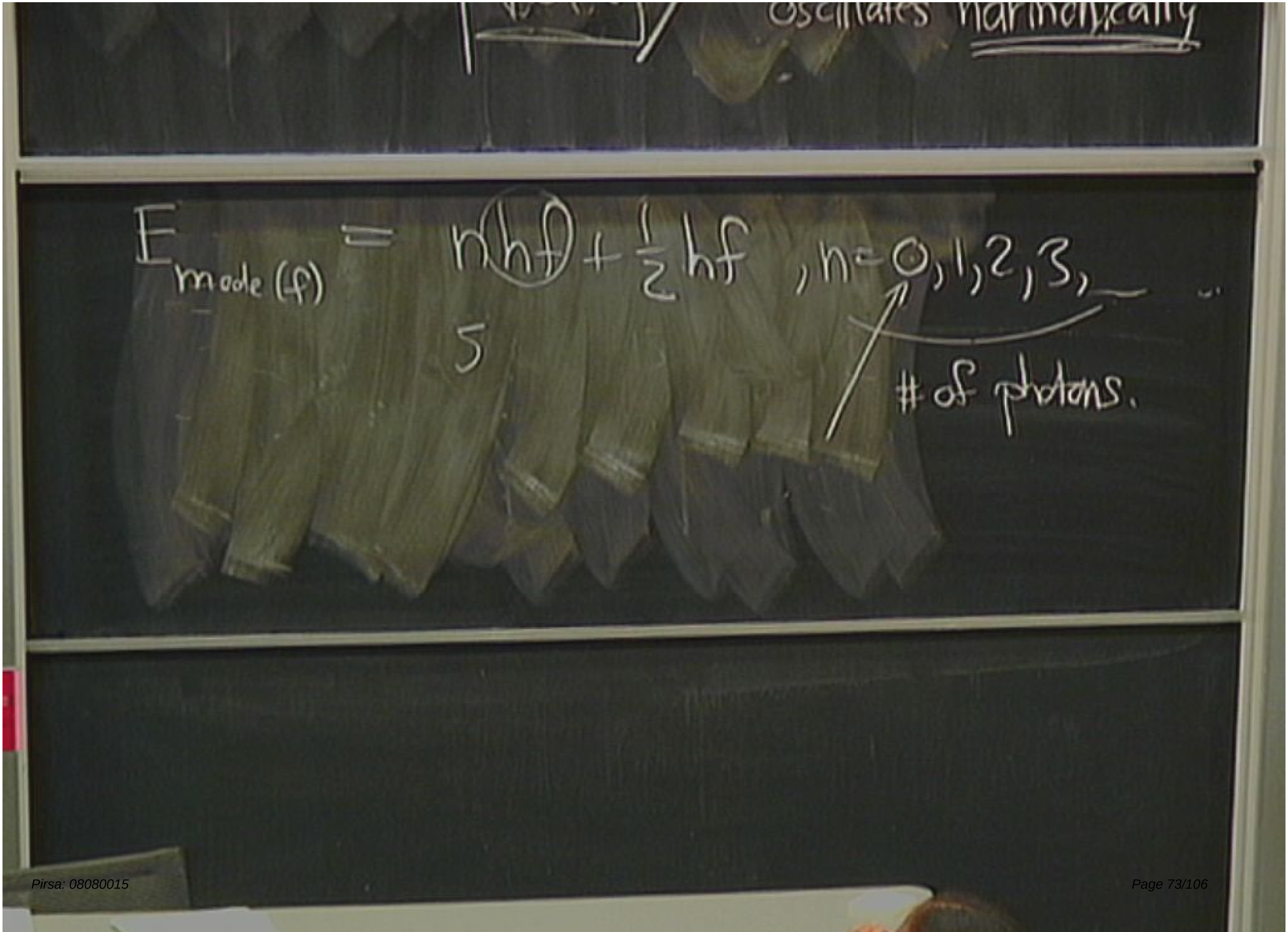
$$E_{mode\,(f)} = nhf + \frac{1}{2}hf \quad, n = 0, 1, 2, 3, \ldots$$

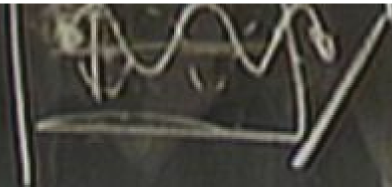
5

oscillates harmonically

$$E_{\text{mode}(f)} = n\,hf + \frac{1}{2}hf \quad , n = 0, 1, 2, 3, \ldots$$

5


oscillates harmonically
E mode (f) = nhf + 1/2 hf , n=0,1,2,3, ...
5
# of photons.



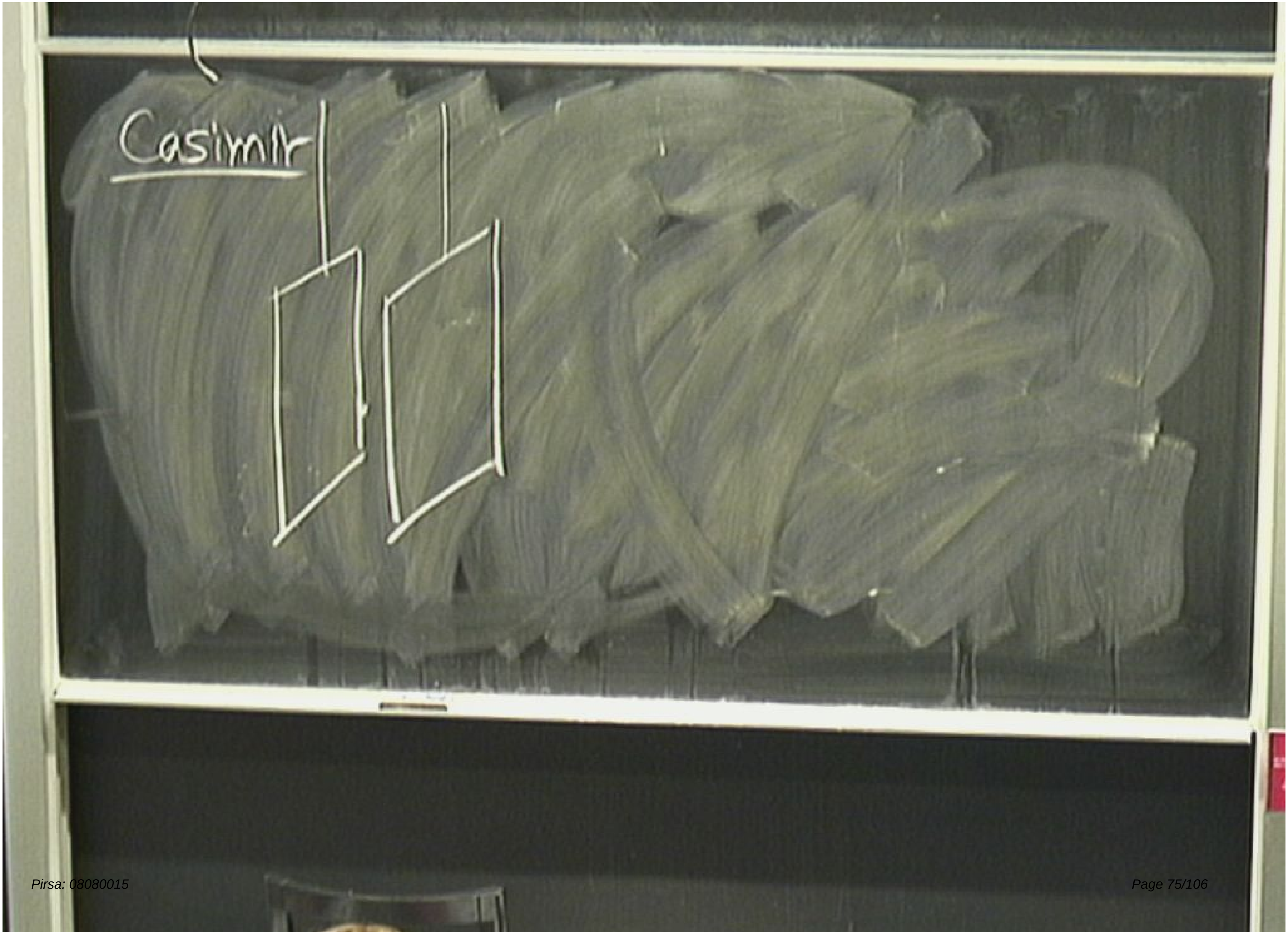
oscilllates harmonically

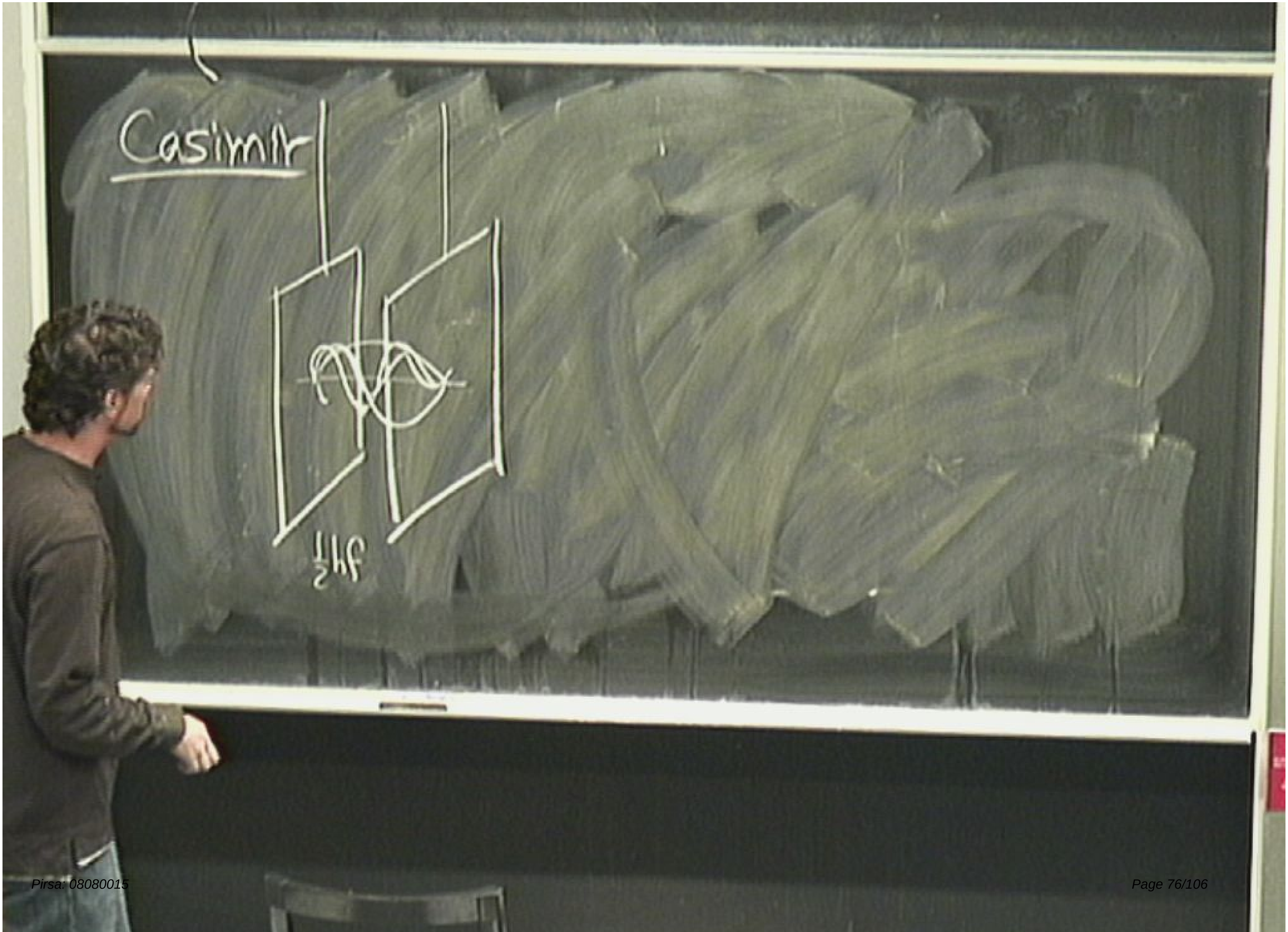
$$E_{mode(f)} = n\,hf + \frac{1}{2}hf \quad , n = 0, 1, 2, 3, \ldots$$

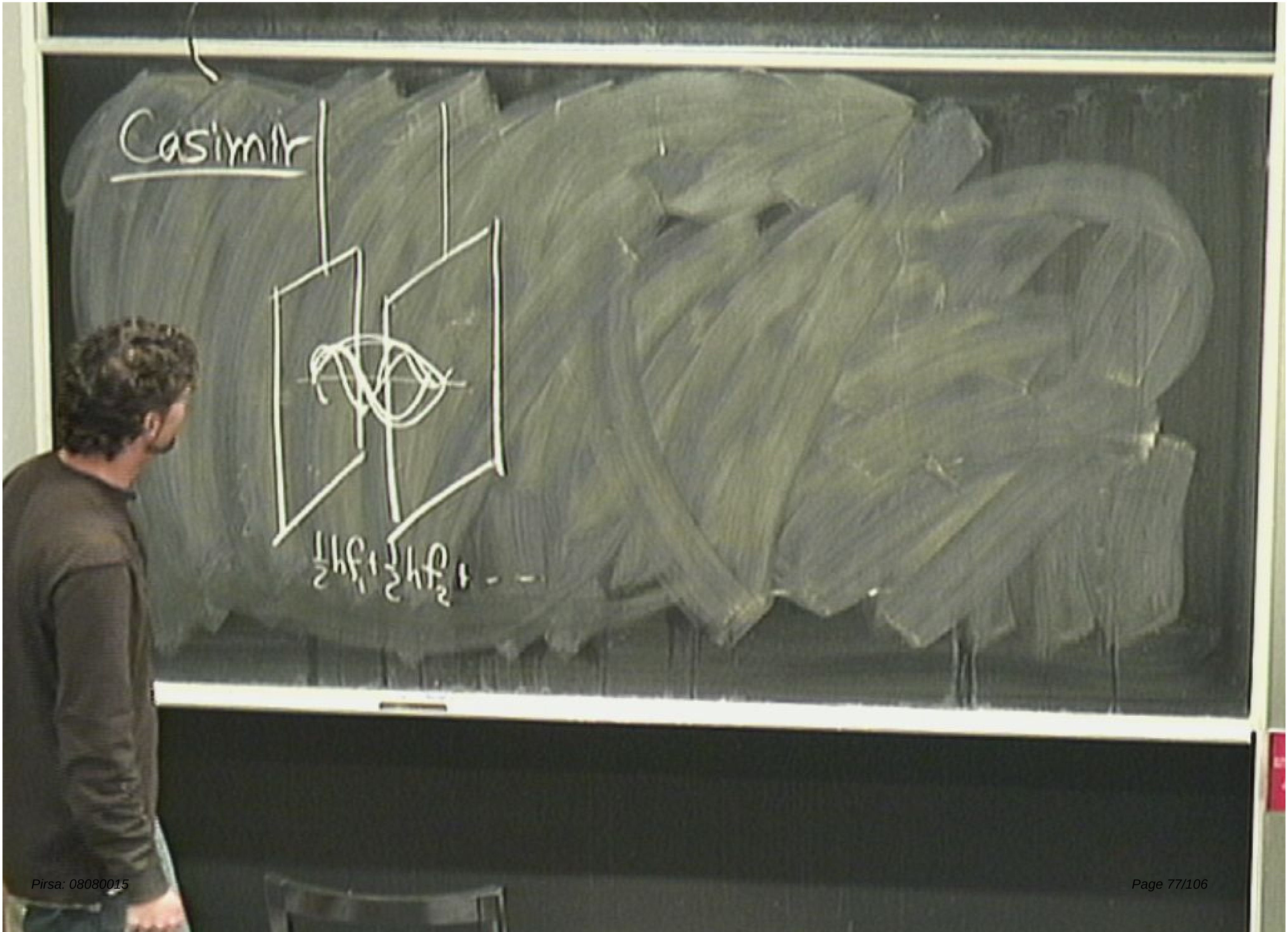
5

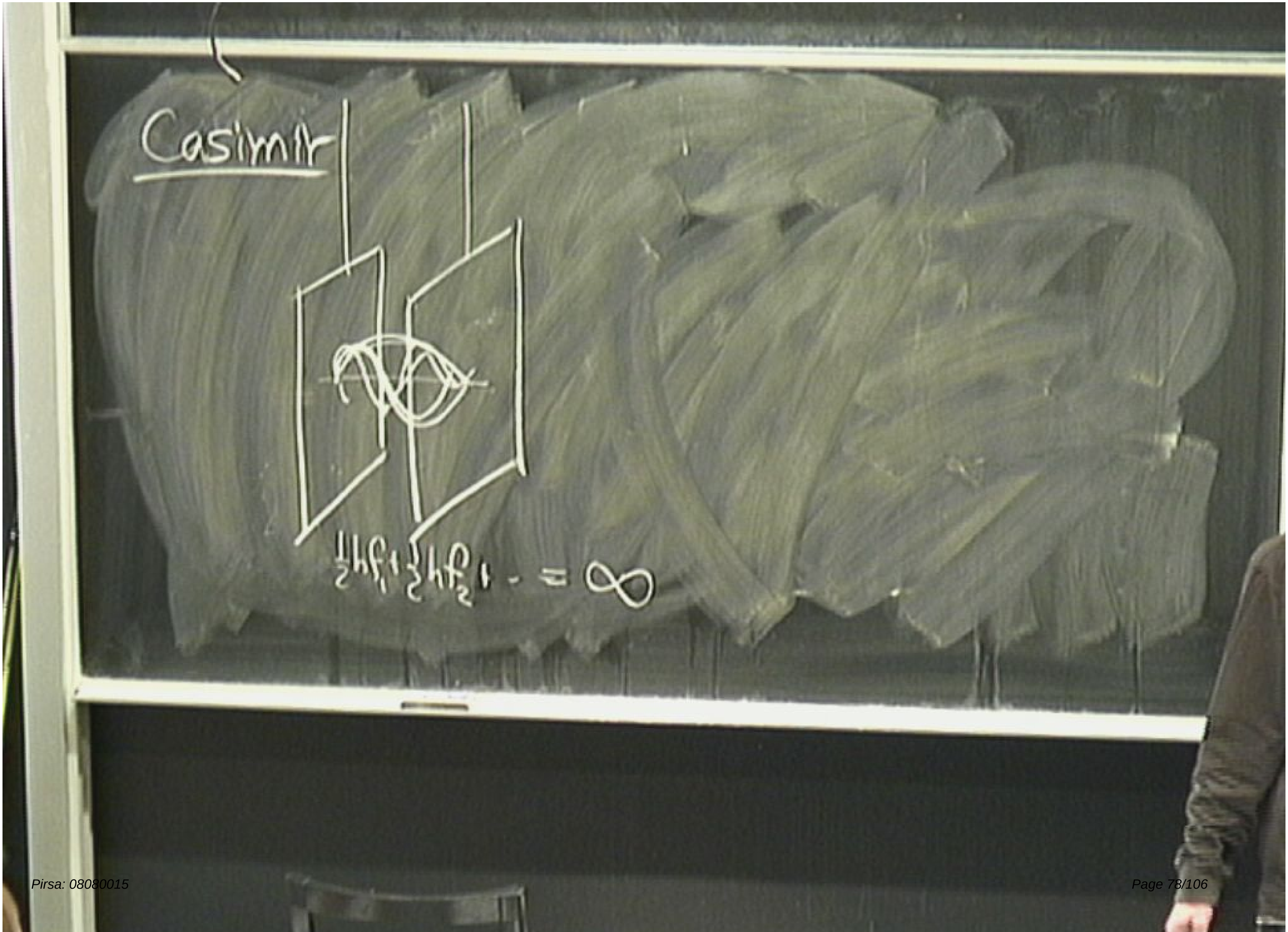
$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

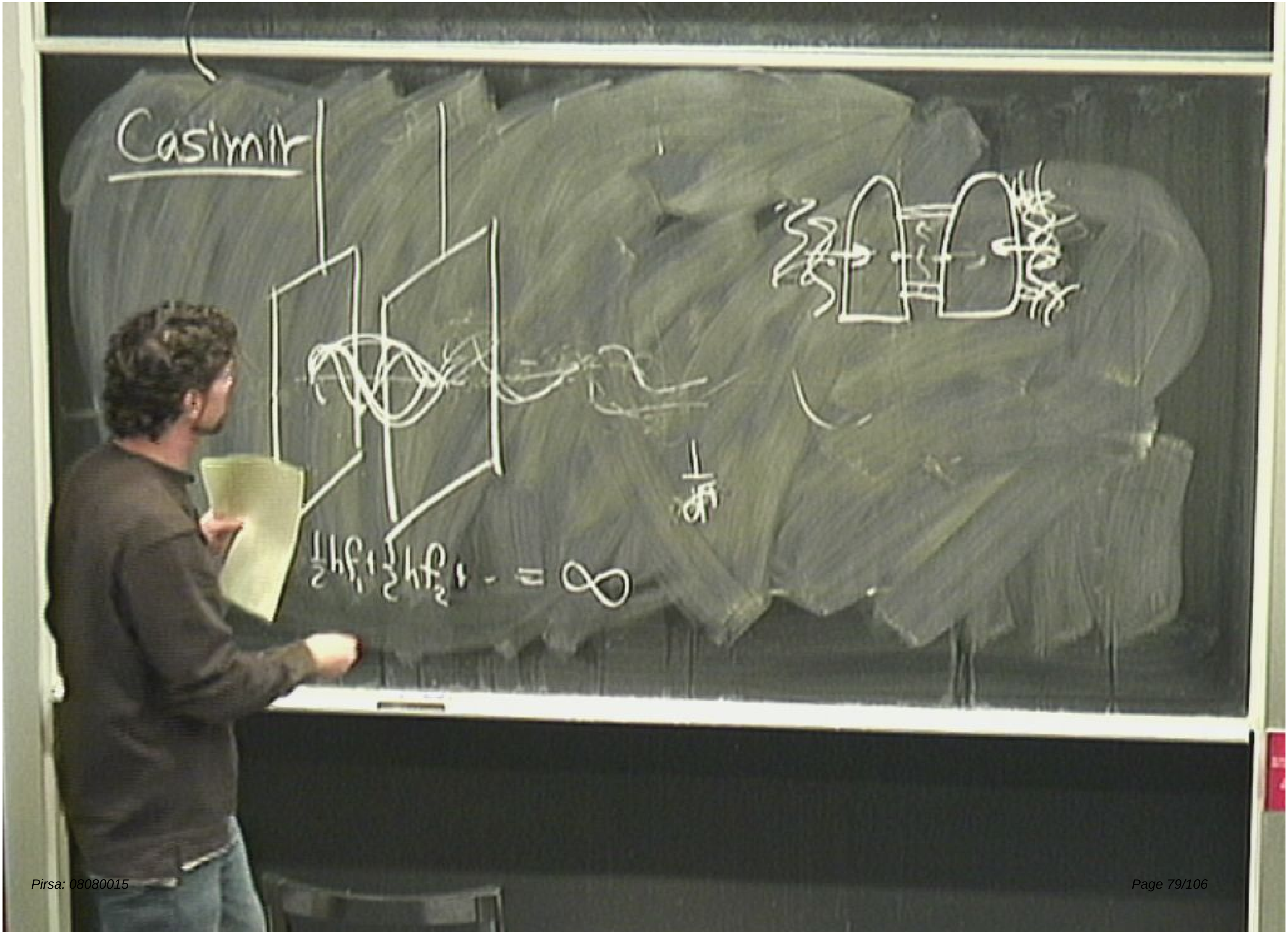
# of photons.

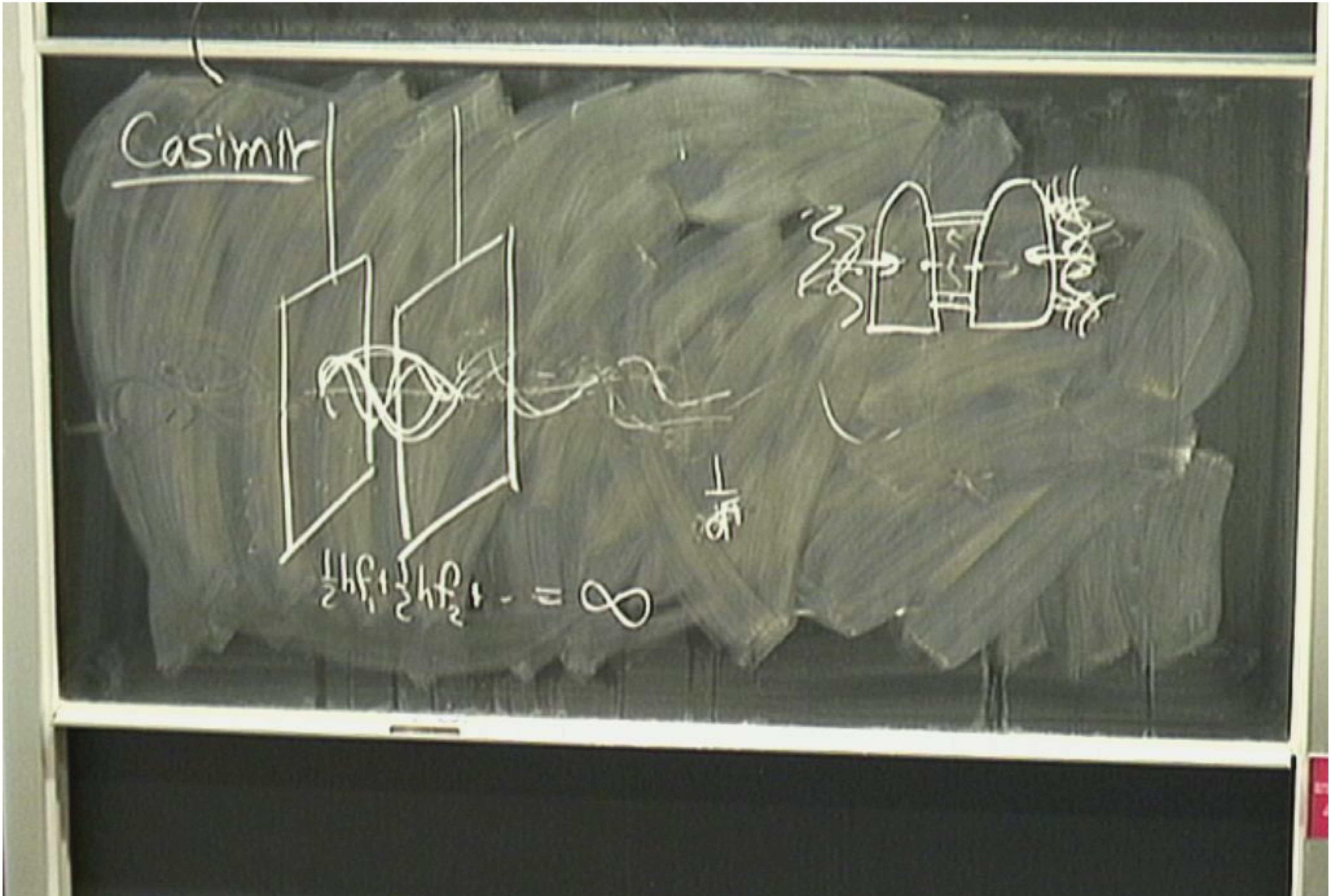

Casimir

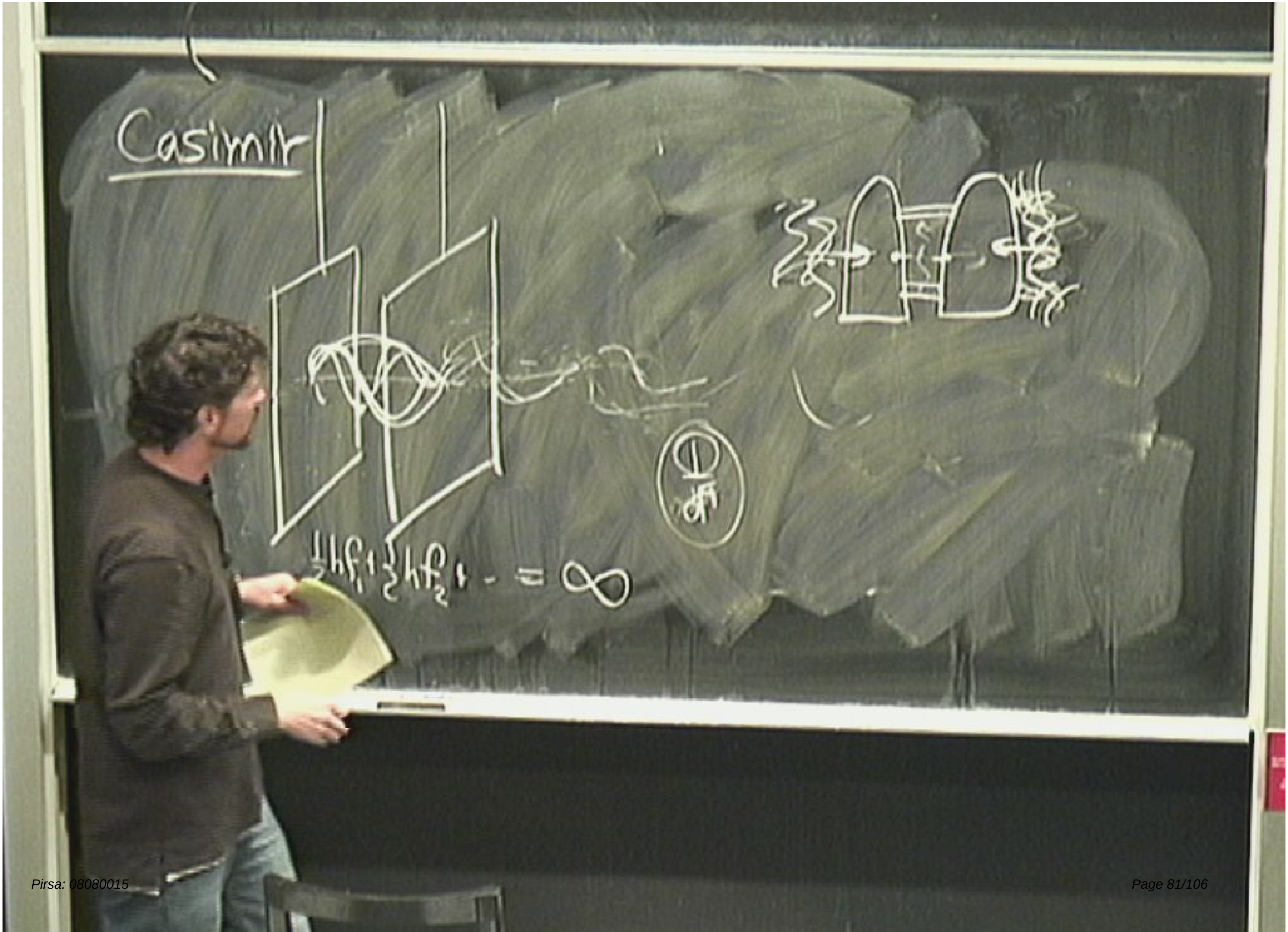

Casimir
½hf

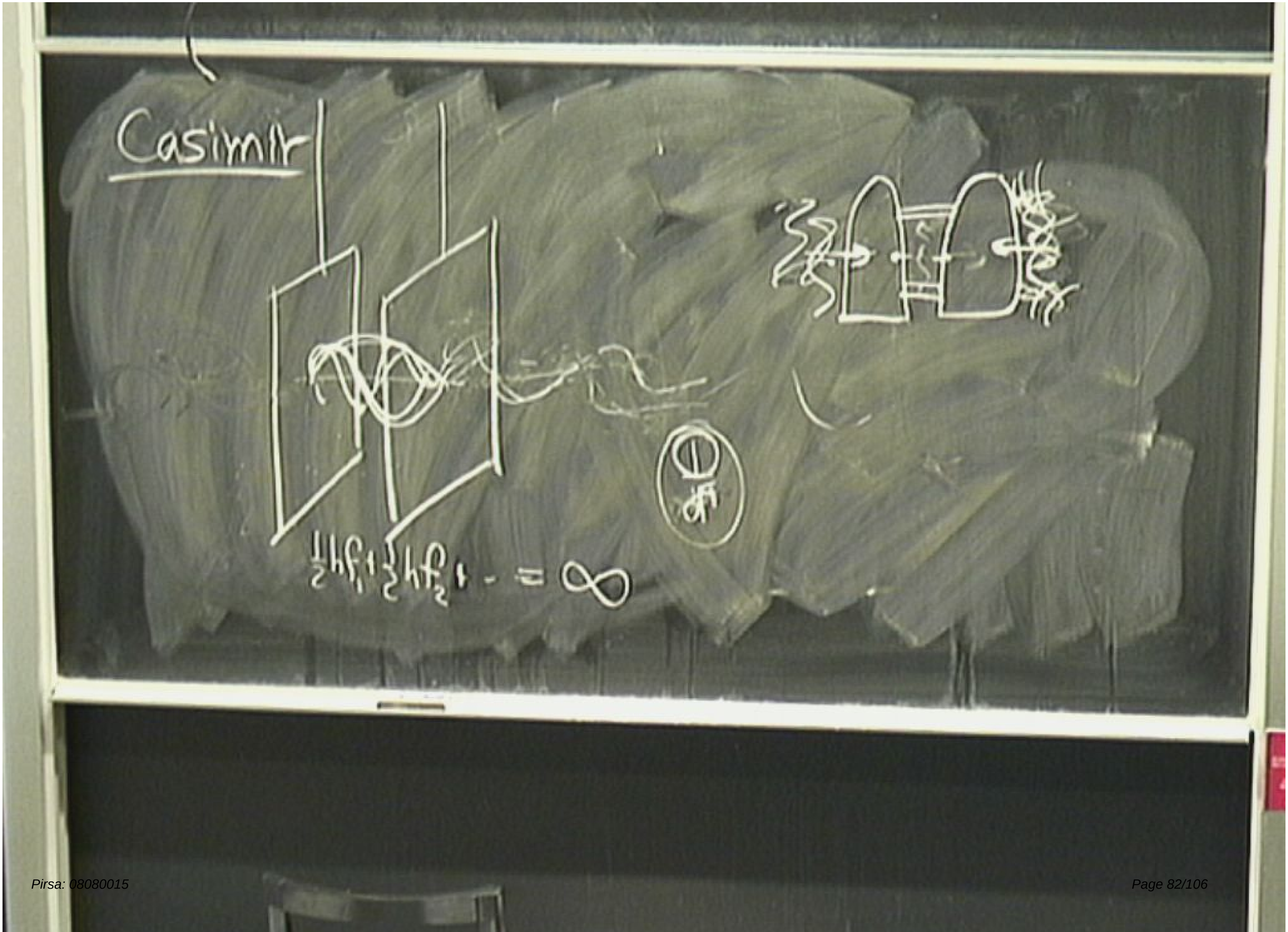

Casimir
$\frac{1}{2}hf_1 + \frac{1}{2}hf_2 + \ldots$

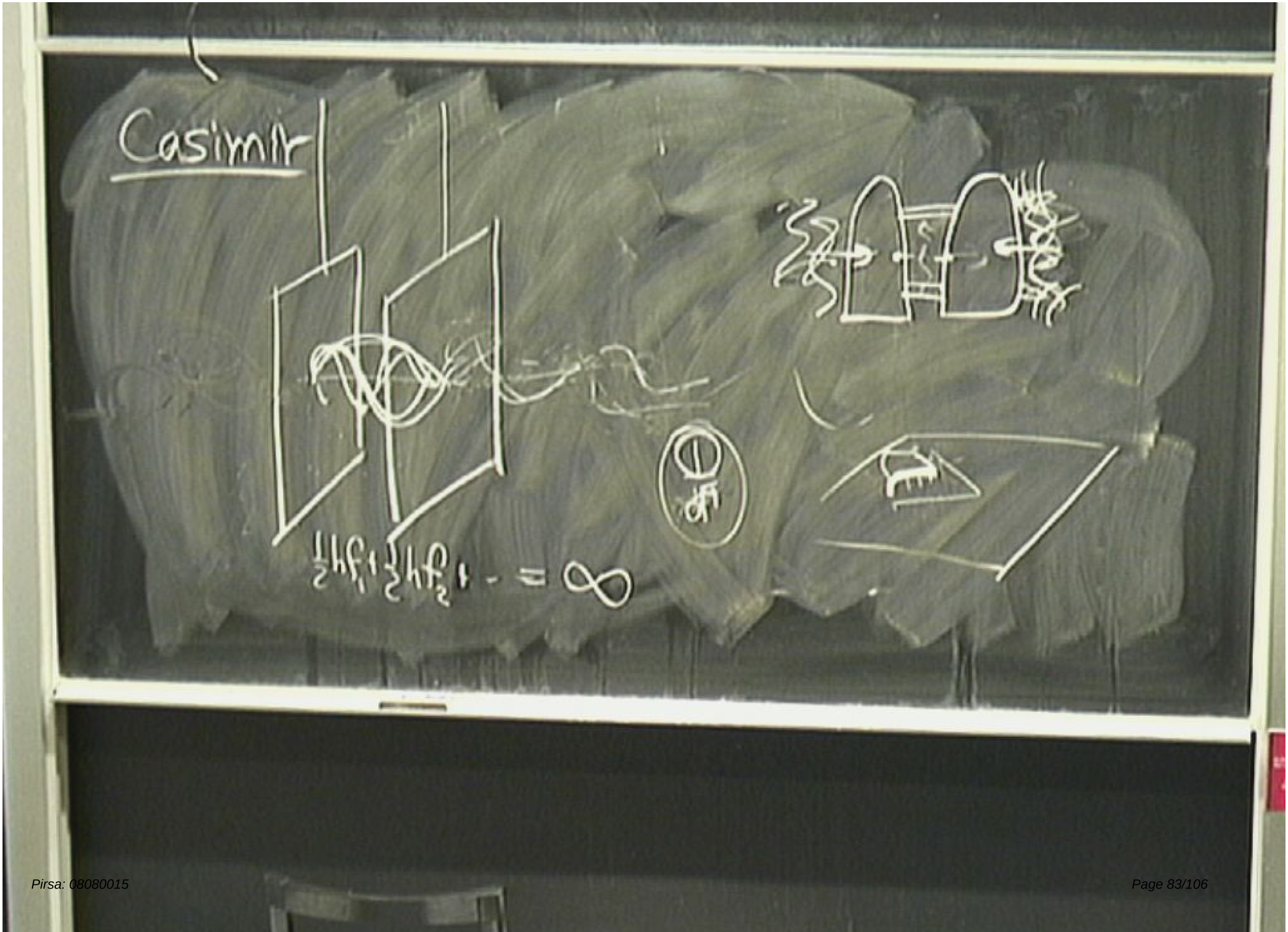

Casimir
$\frac{1}{2}hf_1 + \frac{1}{2}hf_2 + \dots = \infty$


Casimir
$\frac{1}{2}hf_1 + \frac{1}{2}hf_2 + \dots = \infty$

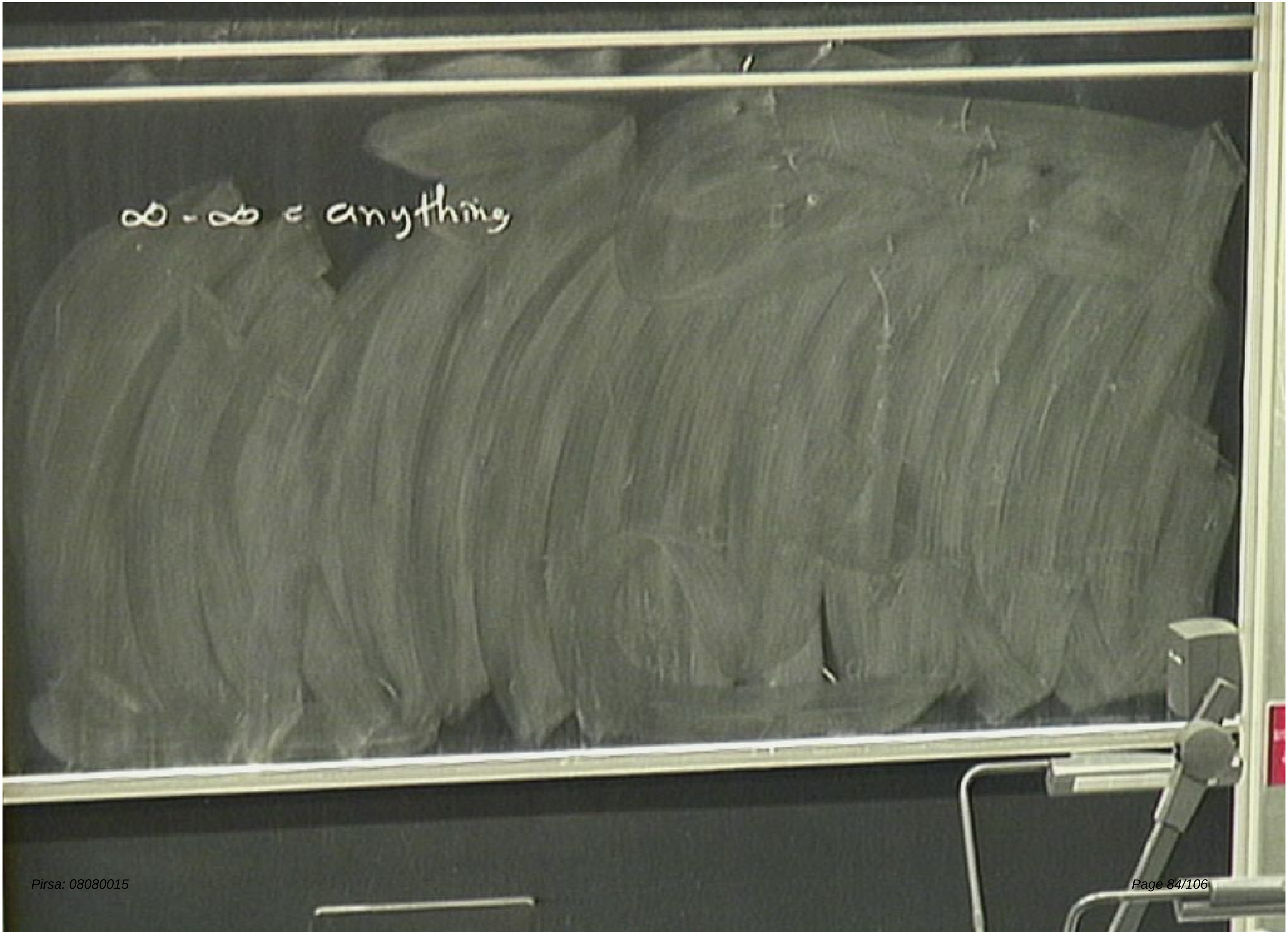

Casimir
1/2 hf1 + 1/2 hf2 + ... = ∞

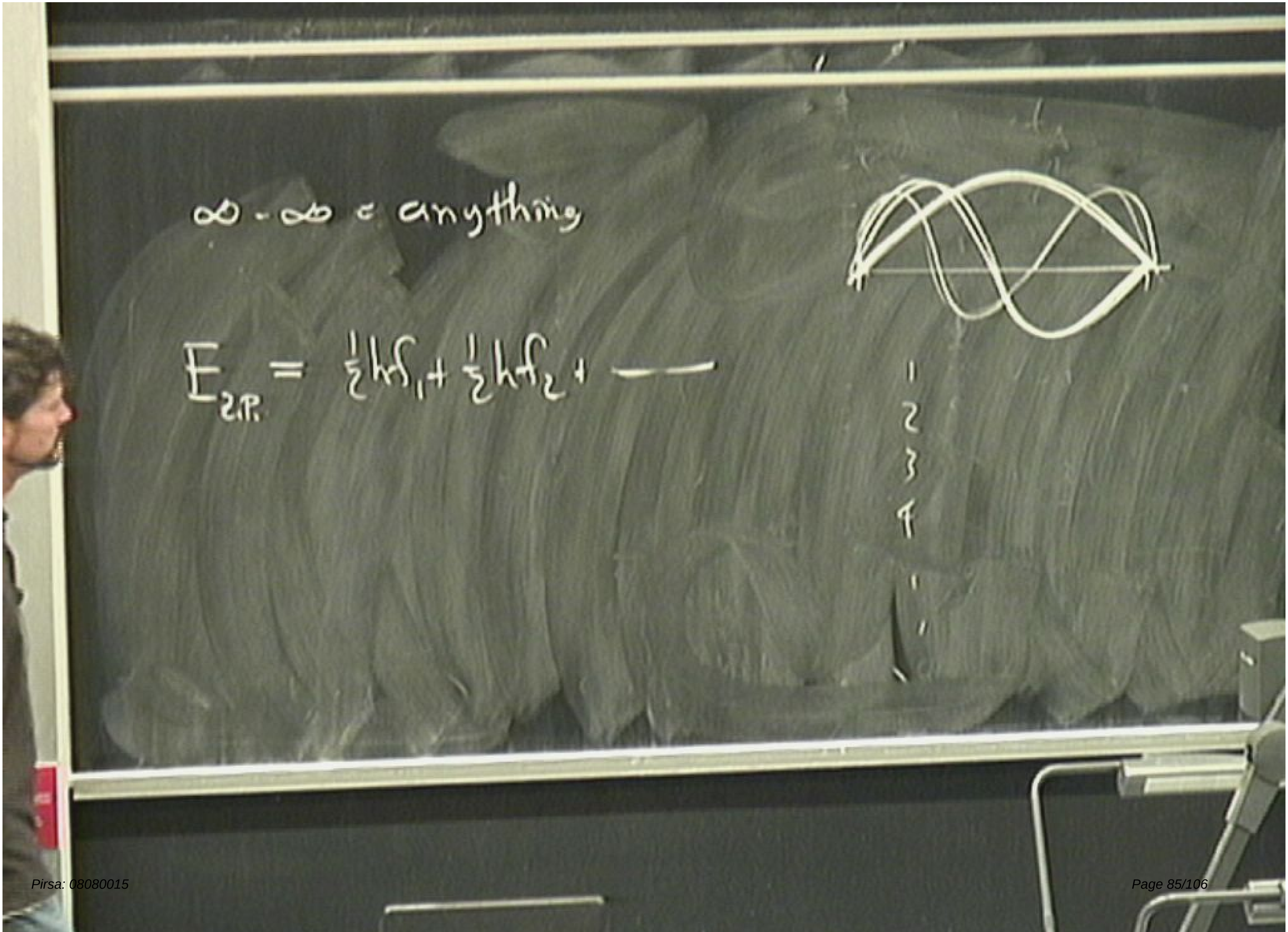

Casimir
$\frac{1}{2}hf_1 + \frac{1}{2}hf_2 + \dots = \infty$


Casimir
½hf₁ + ½hf₂ + ... = ∞



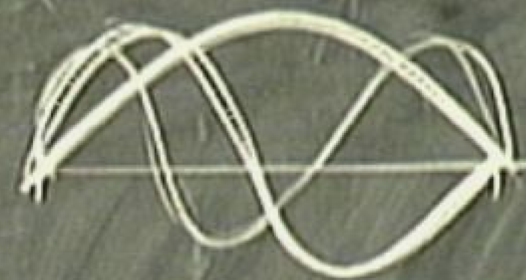
Casimir
$\frac{1}{2}hf_1 + \frac{1}{2}hf_2 + \ldots = \infty$


∞ - ∞ = anything


∞ - ∞ = anything
E_Z.P. = ½hf_1 + ½hf_2 + ——
1
2
3
4

$\infty - \infty = $ anything

$1 \times 2 \times 3 \times \ldots$



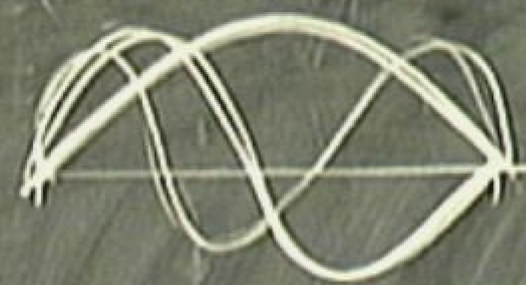
$$E_{2\pi} = \tfrac{1}{2}hf_1 + \tfrac{1}{2}hf_2 + \text{———}$$

$$= (\ )(1+2+3+4+\cdots)$$

1
2
3
4

$\infty - \infty =$ anything

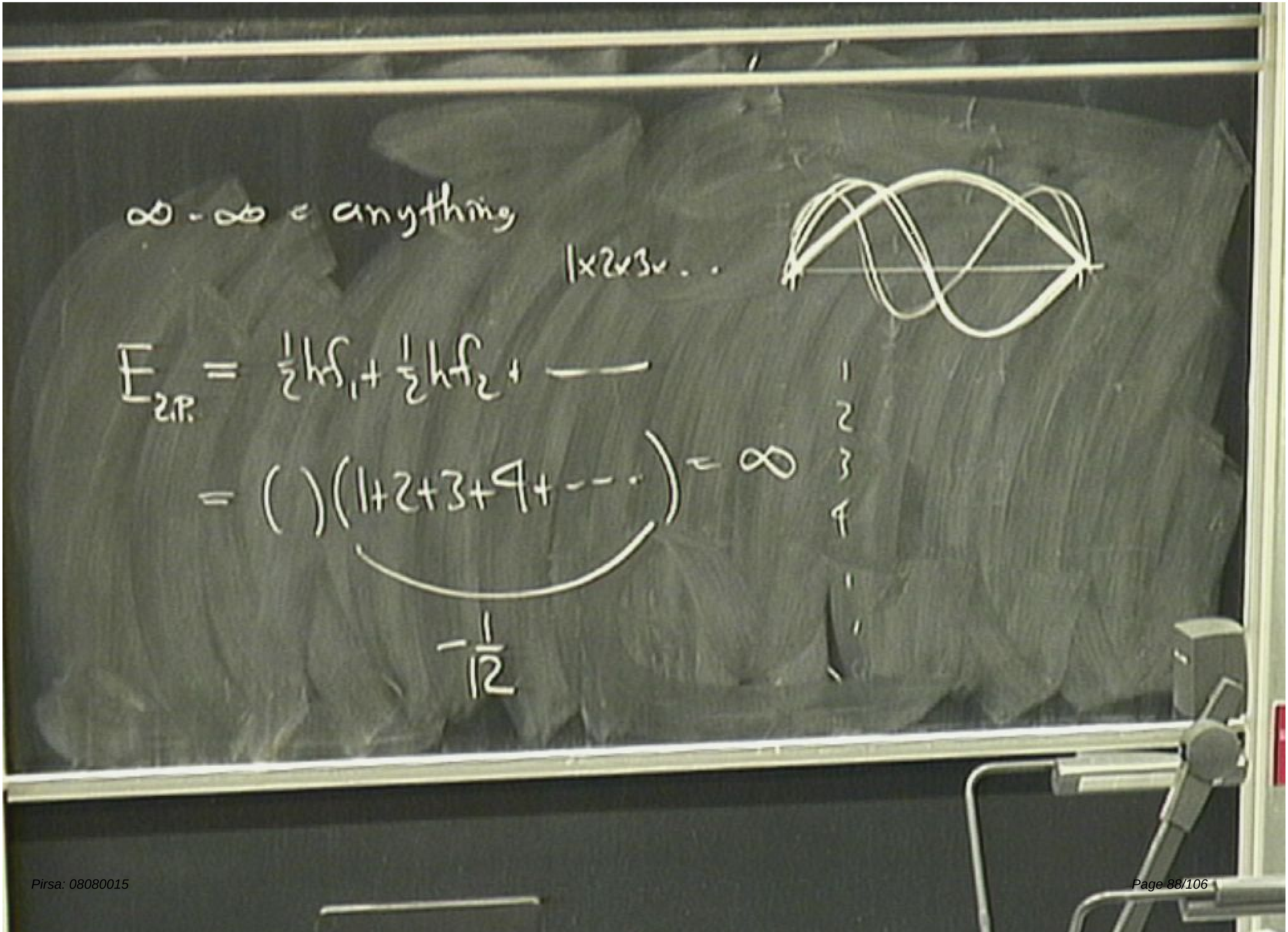
$1 \times 2 \times 3 \times \ldots$

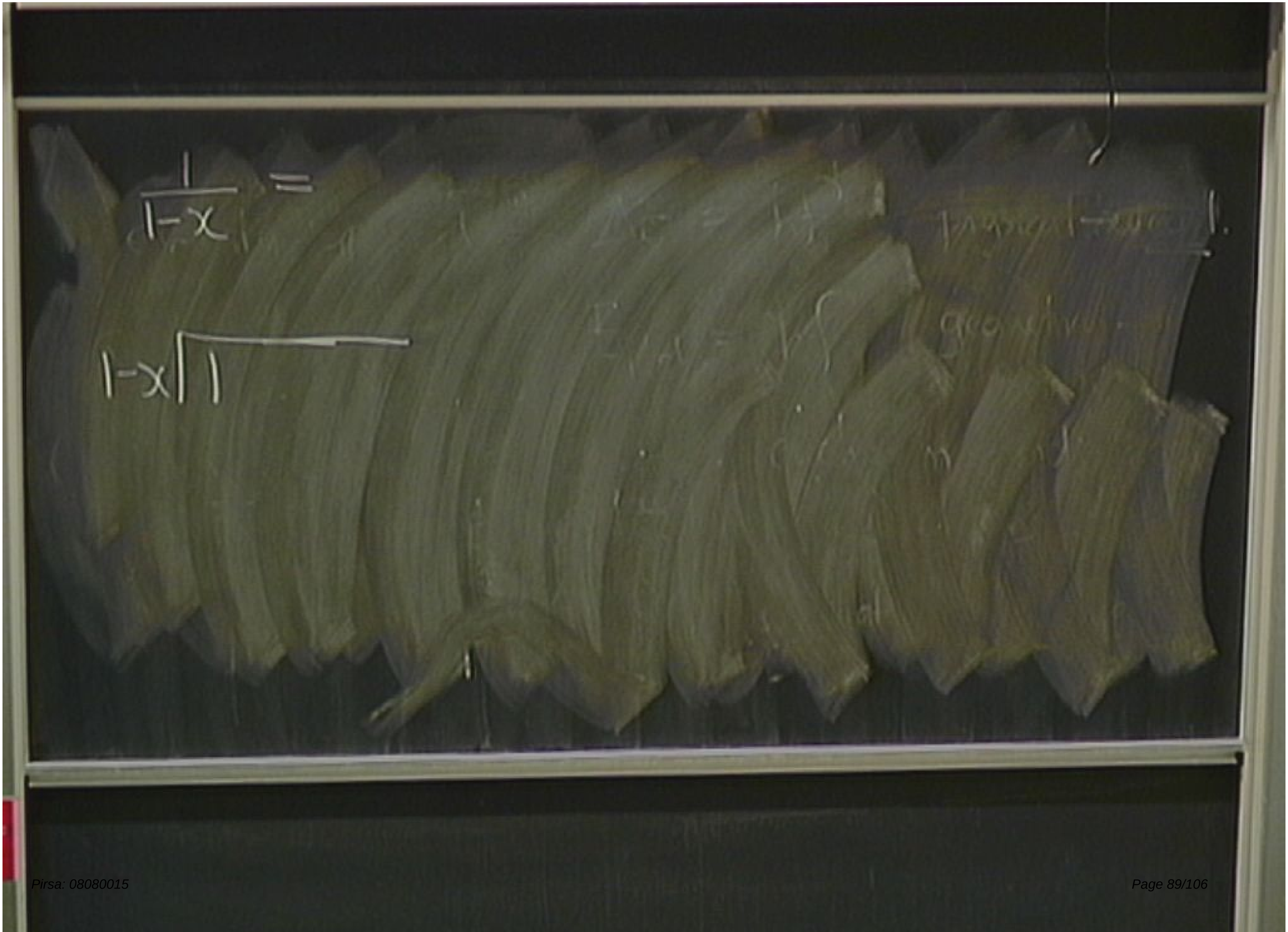


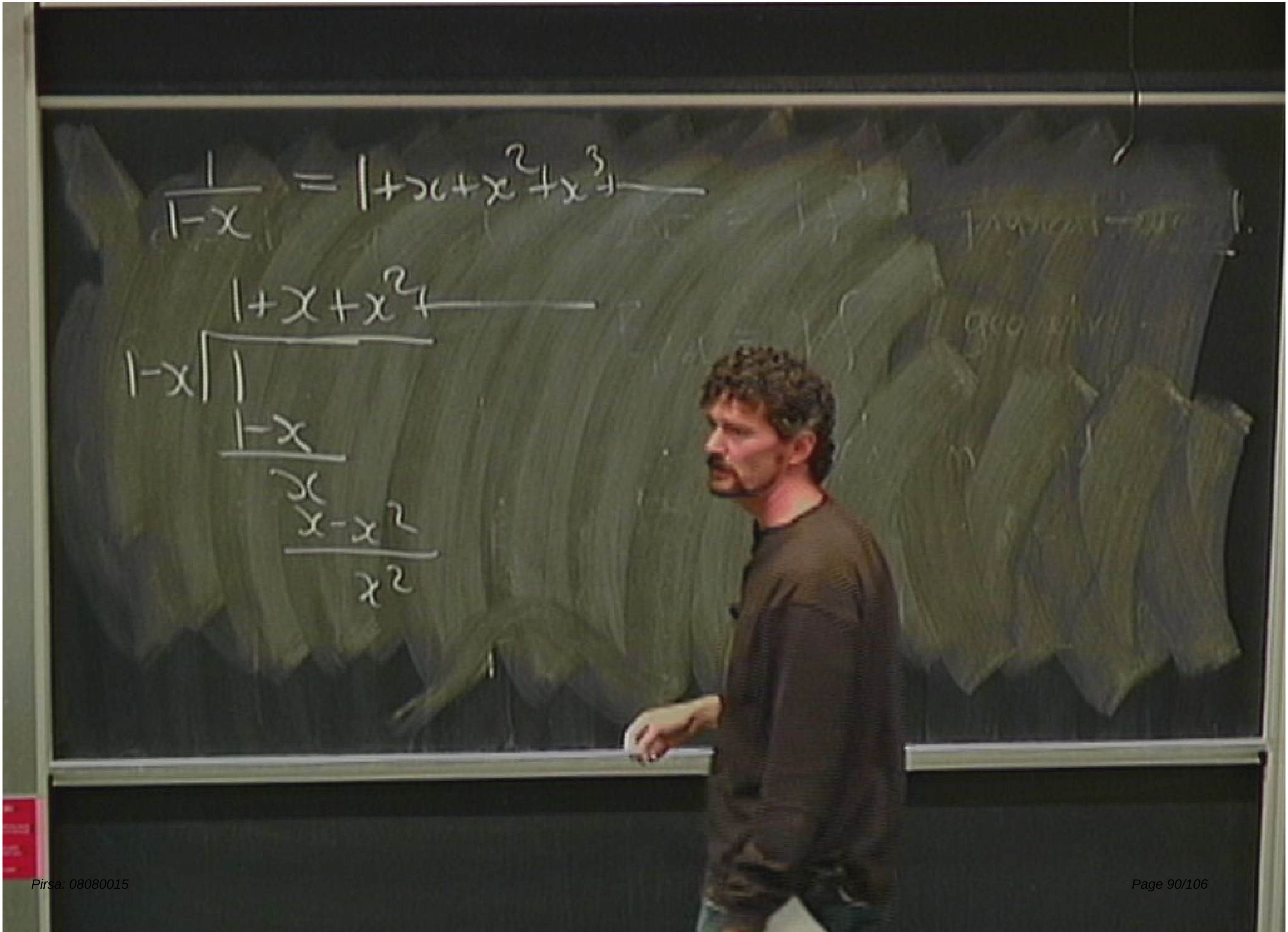
$$E_{Z.P.} = \tfrac{1}{2}hf_1 + \tfrac{1}{2}hf_2 + \_\_\_\_$$

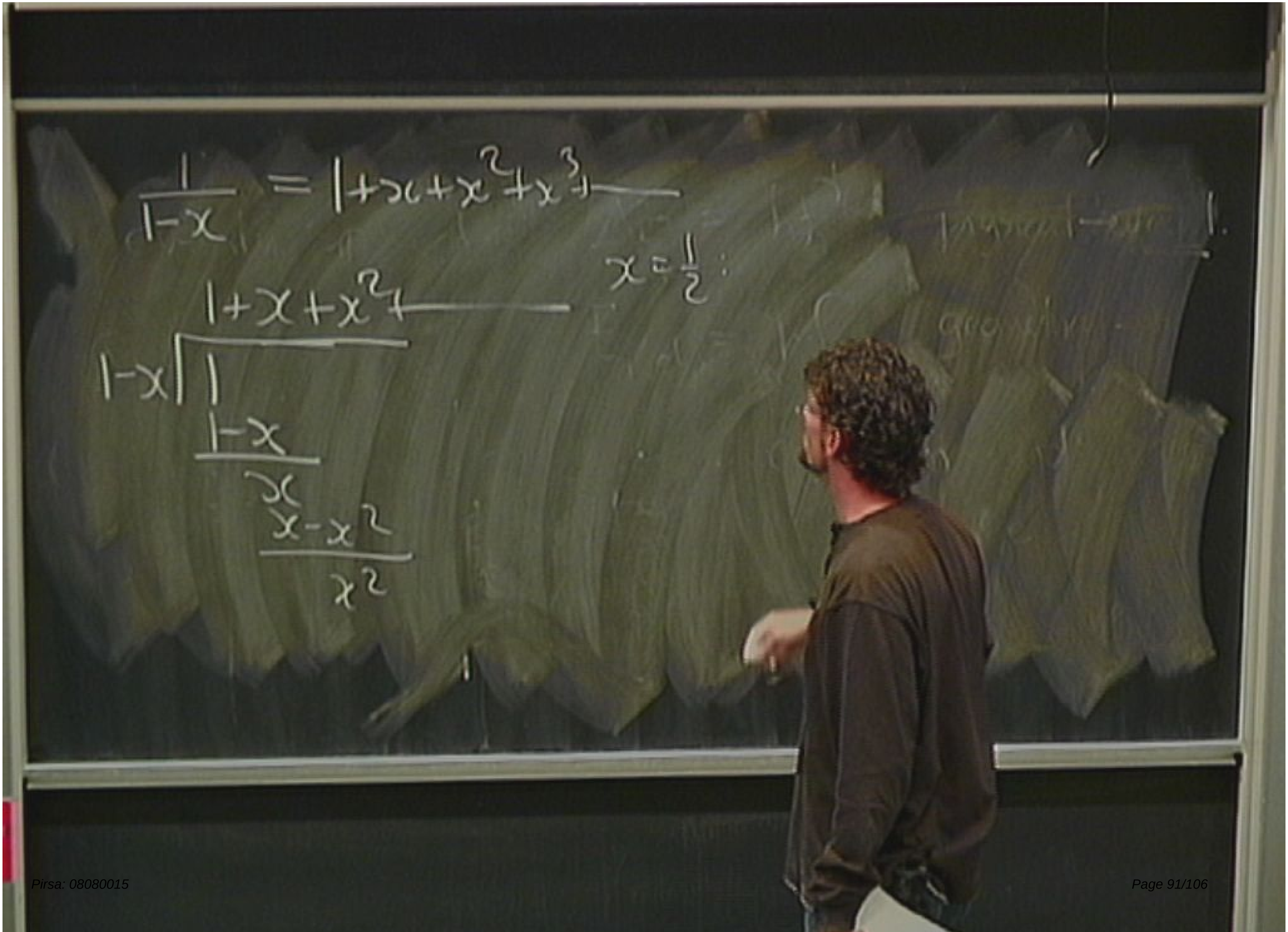
$$= (\ )(1+2+3+4+\cdots) = \infty$$

1
2
3
4
⋮


∞ - ∞ = anything
1×2×3×. .
E_ZP = ½hf₁ + ½hf₂ + ———
= ( )(1+2+3+4+ - - -) = ∞
-1/12
1
2
3
4


1/(1-x) =
1-x | 1

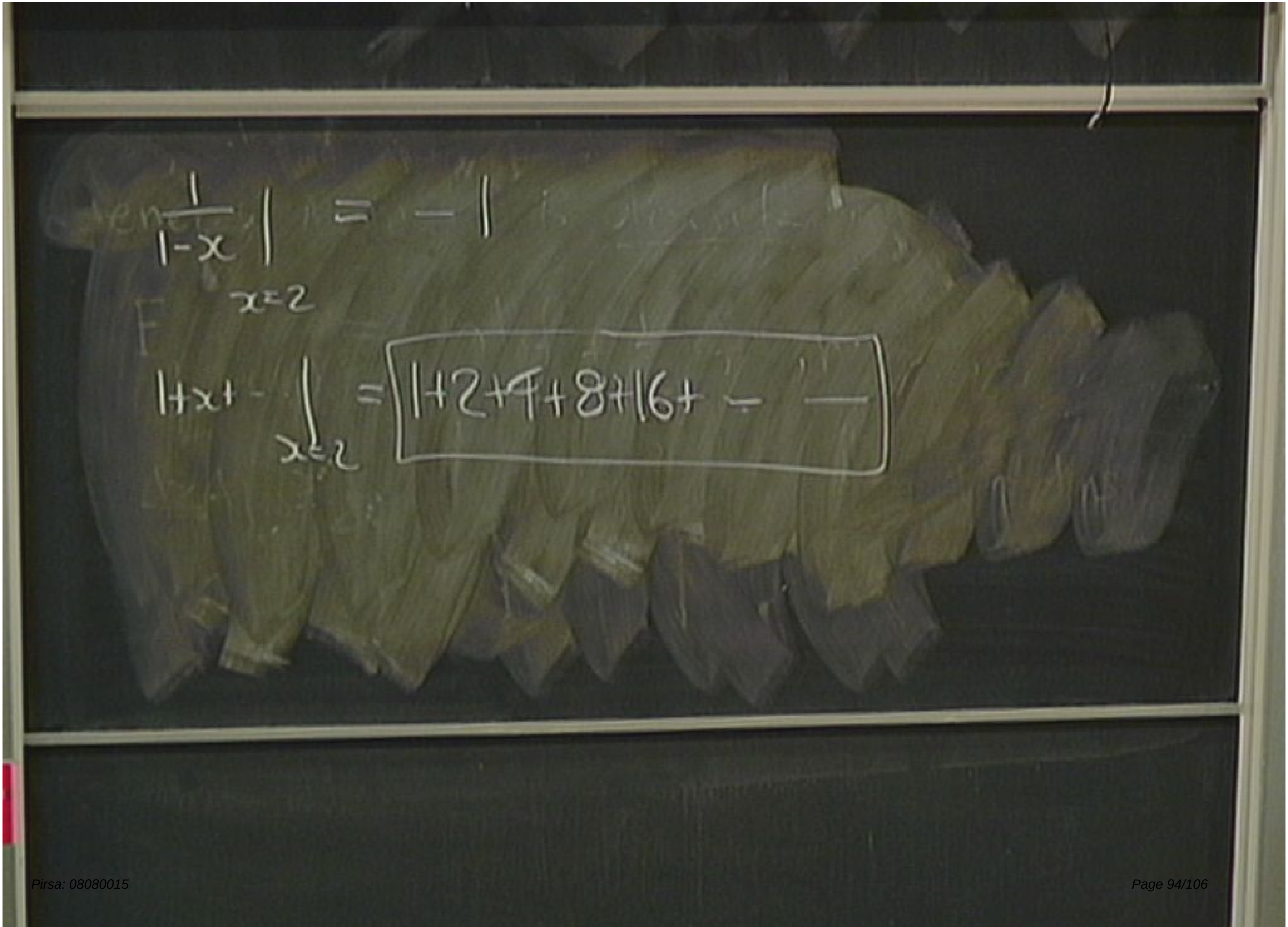

1/(1-x) = 1+x+x^2+x^3+
1+x+x^2+
1-x | 1
1-x
x
x-x^2
x^2


1/(1-x) = 1+x+x^2+x^3+
x = 1/2 :
1+x+x^2+
1-x | 1
1-x
x
x-x^2
x^2

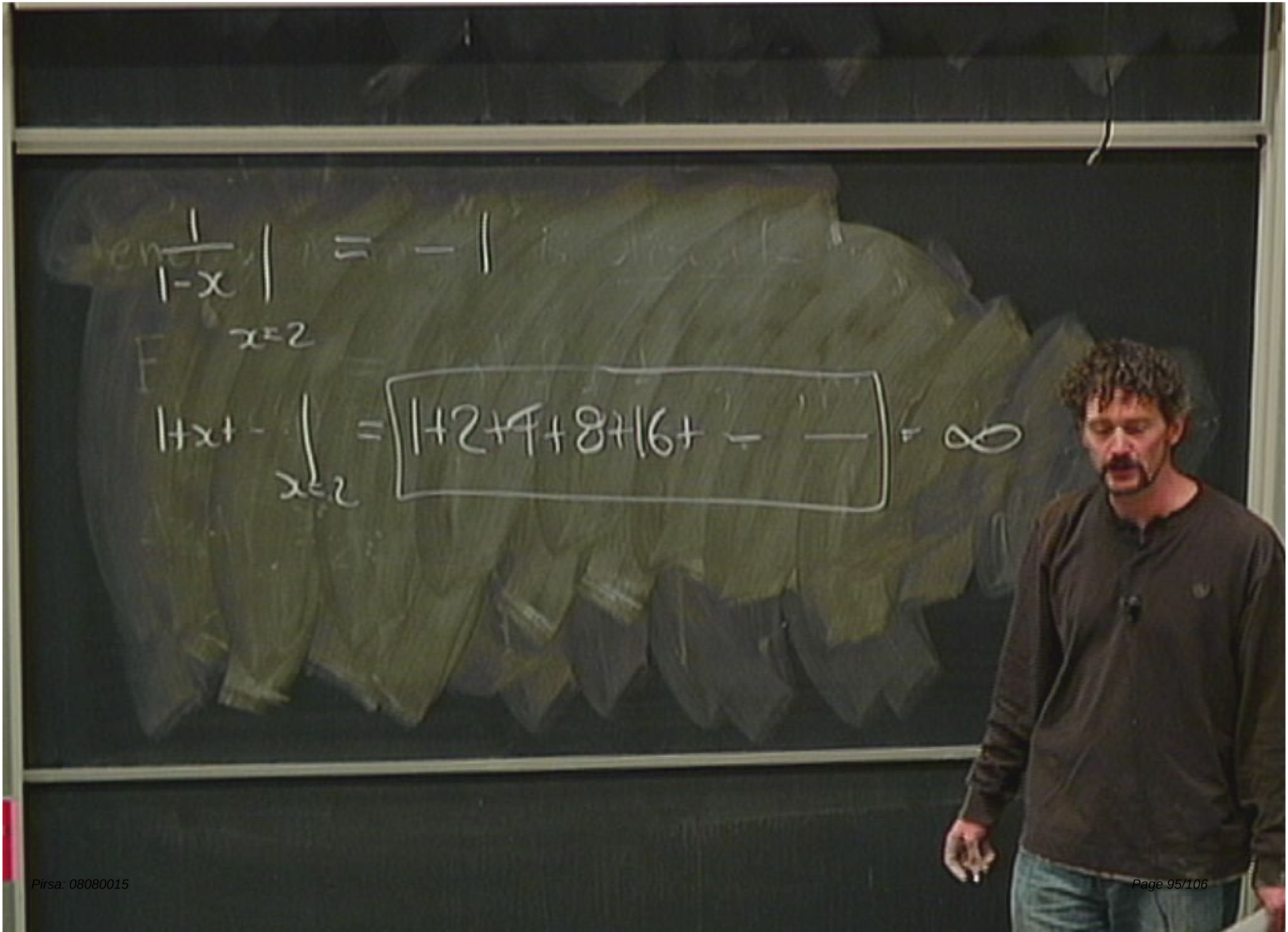
$$\left.\frac{1}{1-x}\right|_{x=2} =$$

$$\left.\frac{1}{1-x}\right|_{x=2} = -1$$

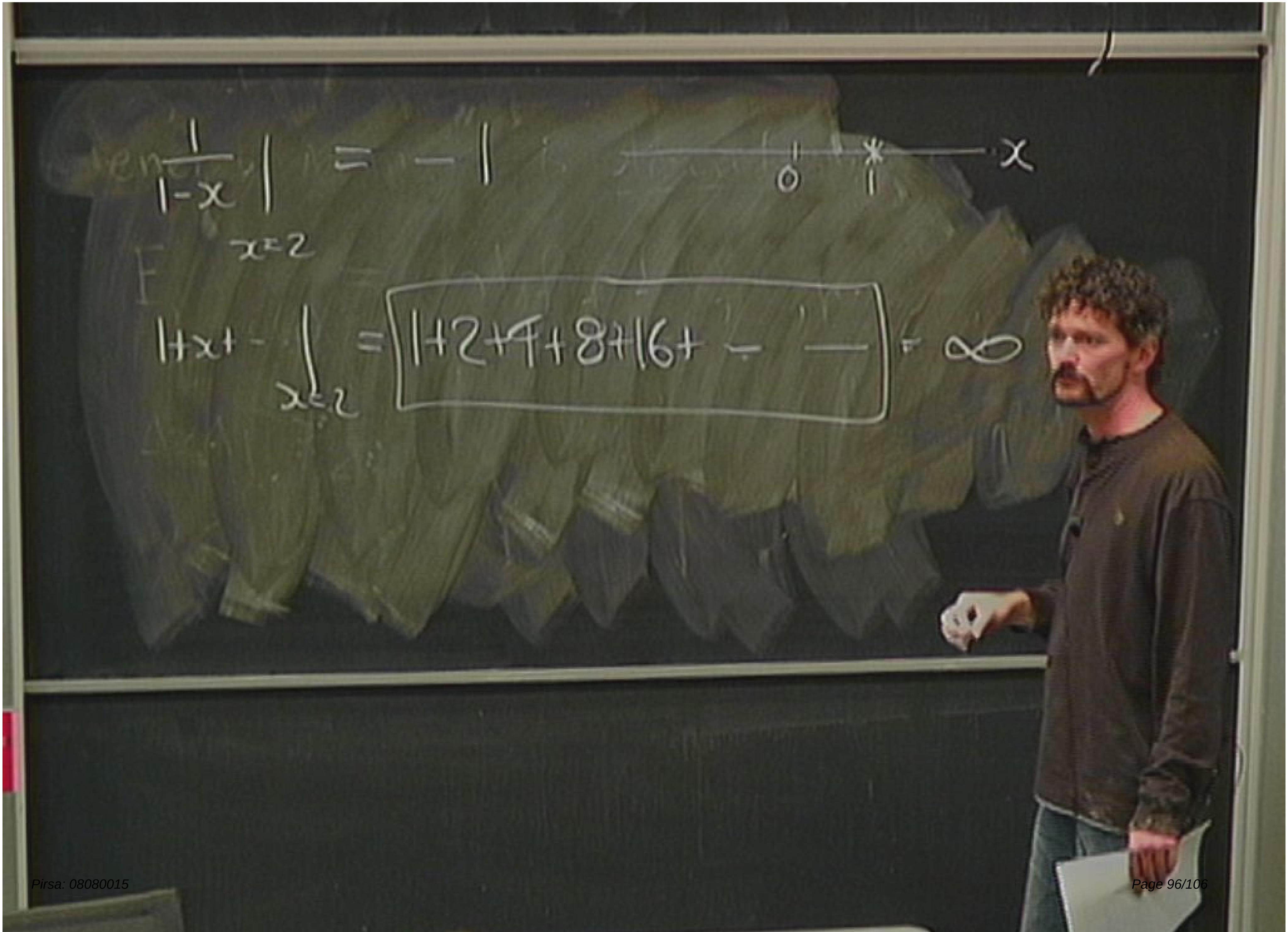
$$\left.1+x+\cdots\right|_{x=2} = 1+2+4+8+16+\cdots$$

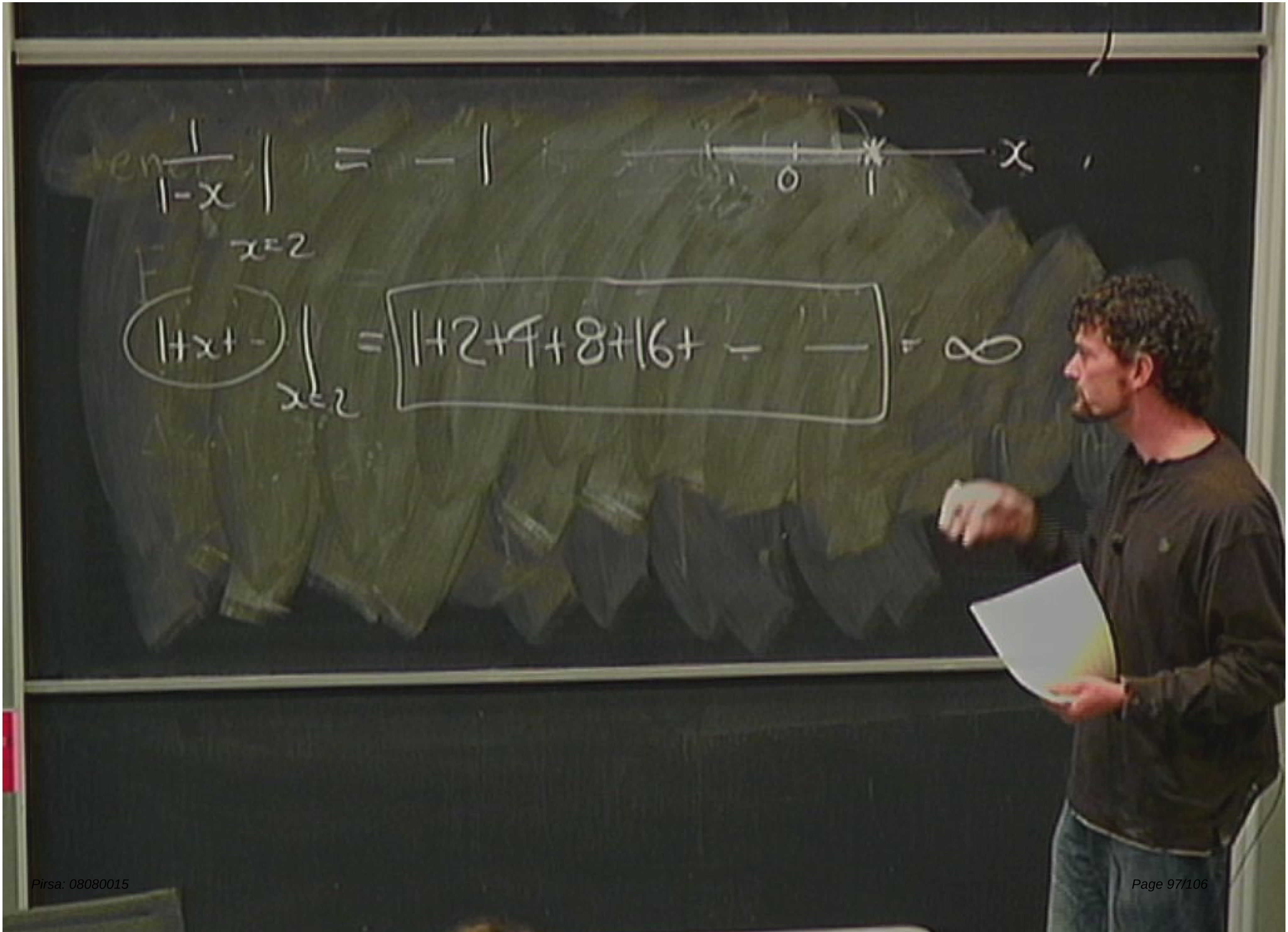


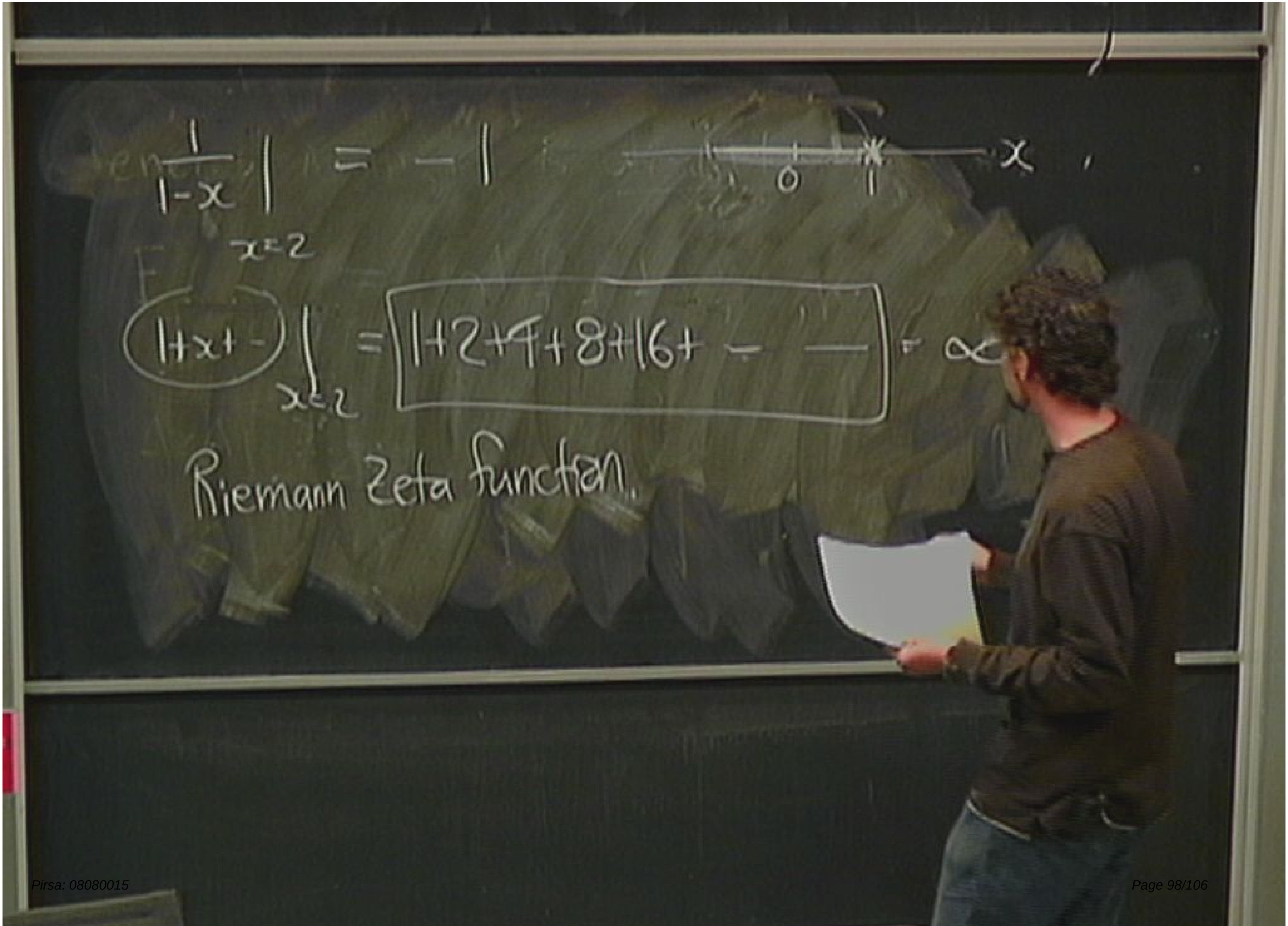
$\frac{1}{1-x}\Big|_{x=2} = -1$
$1+x+\cdots\Big|_{x=2} = 1+2+4+8+16+\cdots$

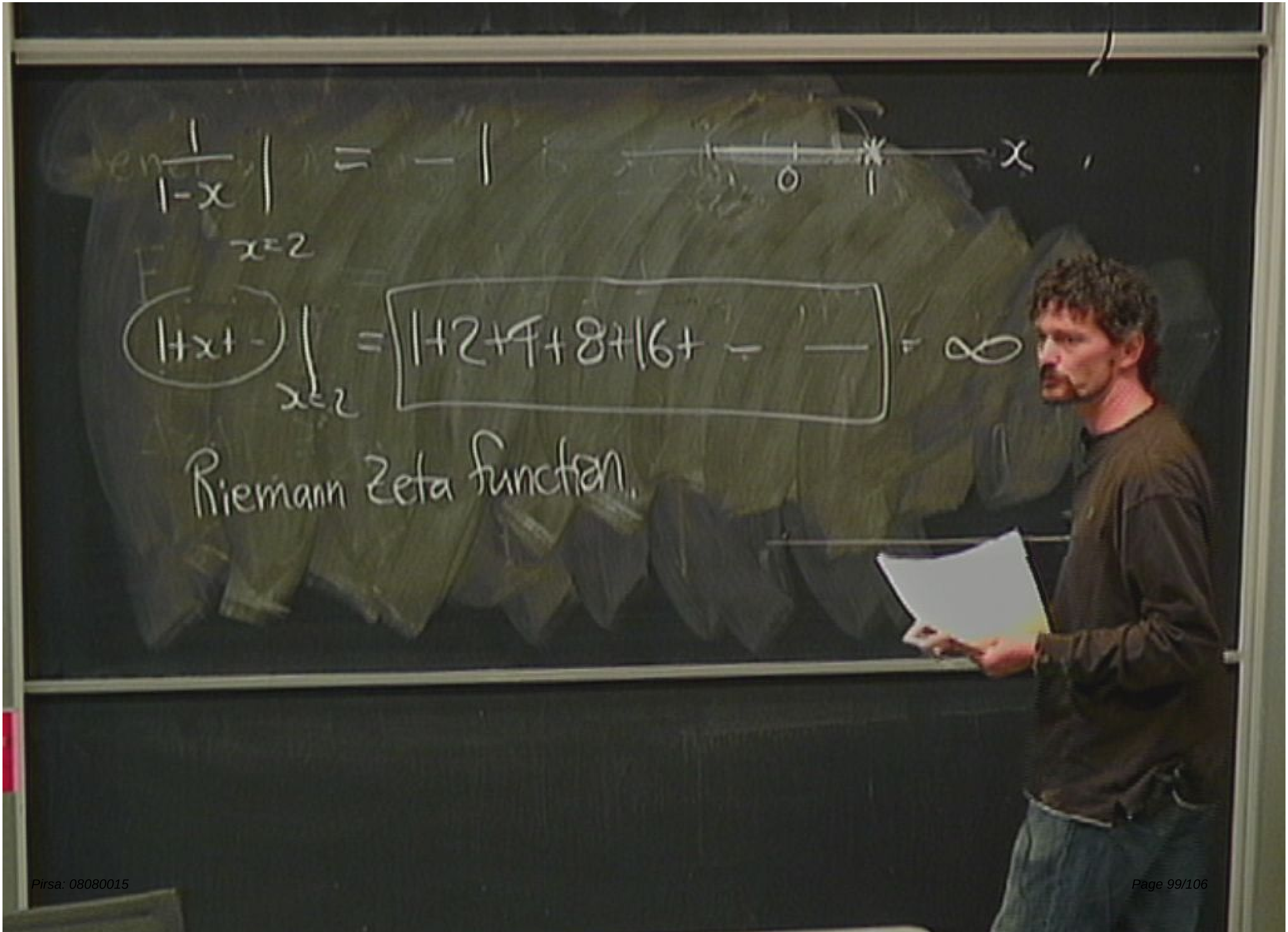


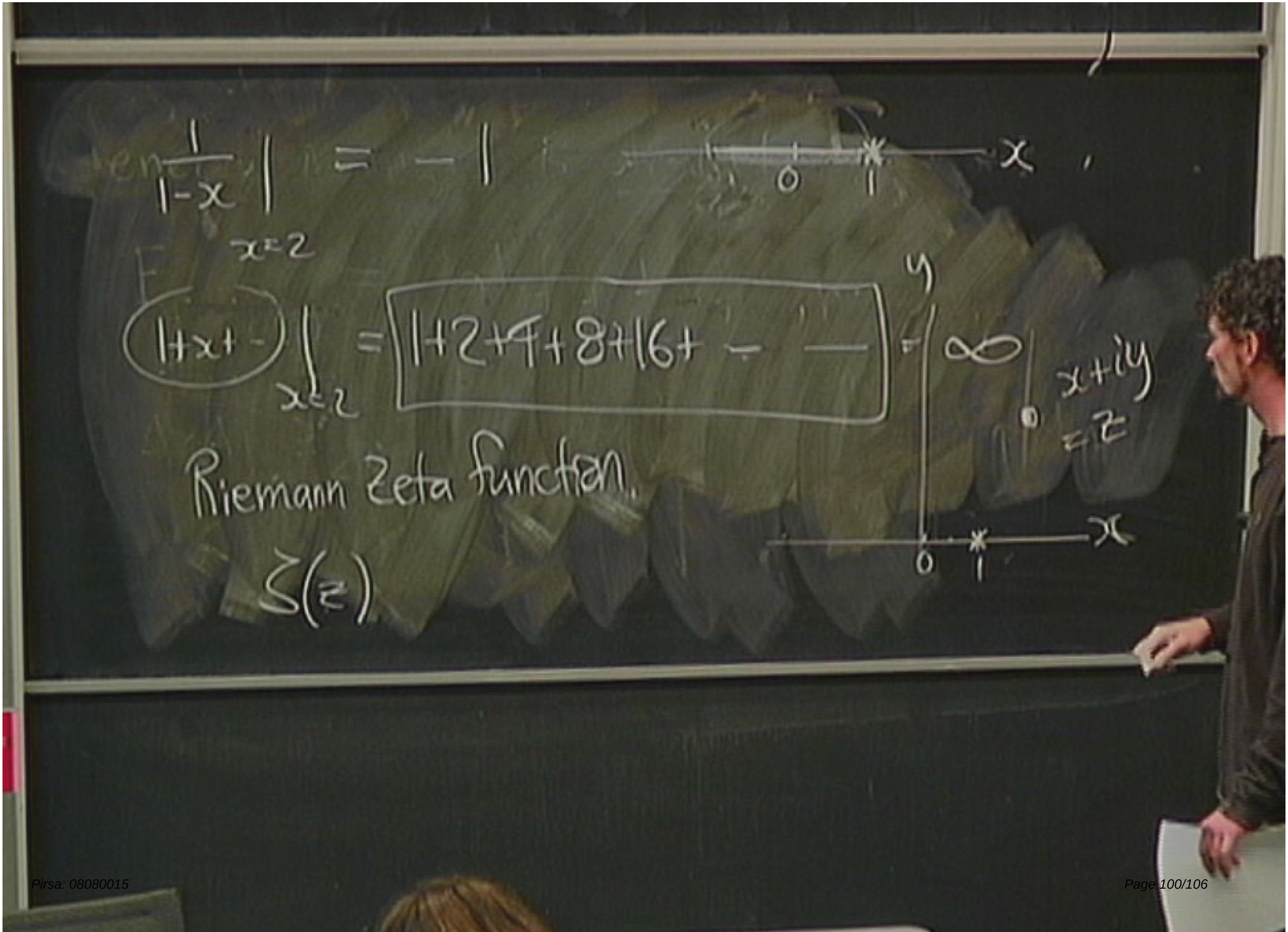
1/(1-x) | x=2 = -1
1+x+ ... | x=2 = 1+2+4+8+16+ ... = ∞

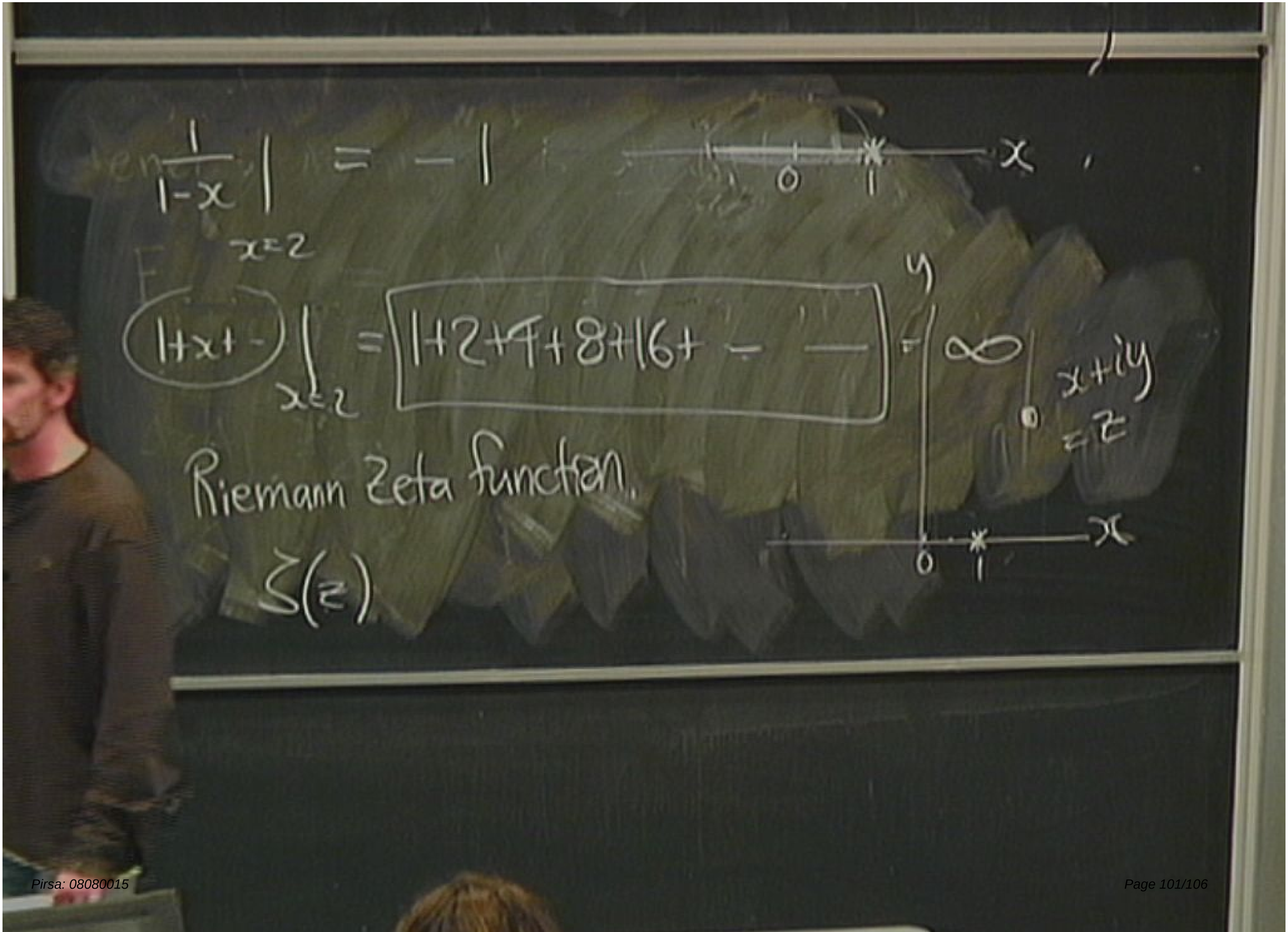

1/(1-x) | x=2 = -1
0
1
x
1+x+... | x=2 = 1+2+4+8+16+... = ∞


1/(1-x) | = -1
x=2
0
1
x
1+x+… | = 1+2+4+8+16+… = ∞
x=2

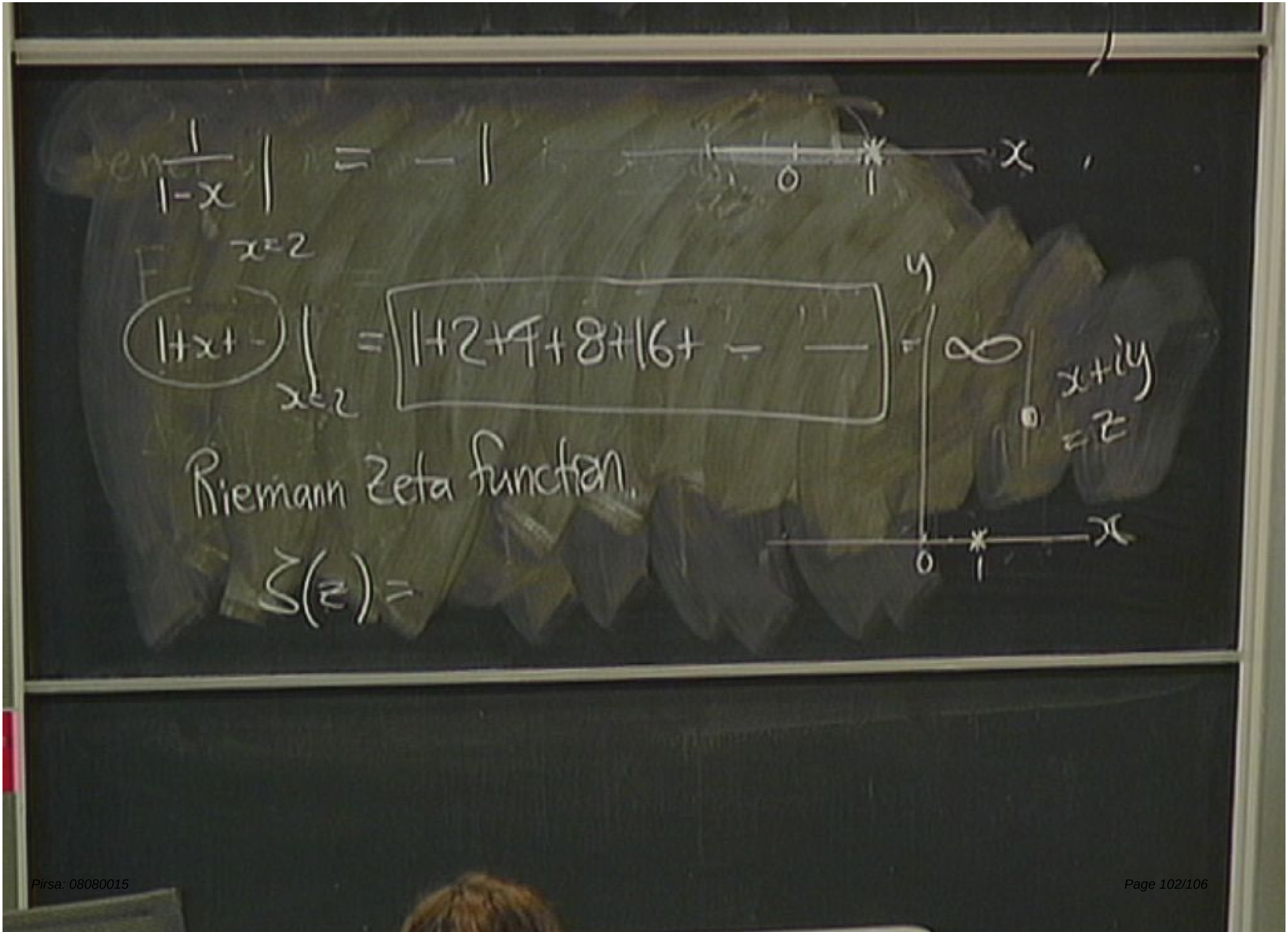

1/(1-x) | x=2 = -1
0 1 x
1+x+ ... | x=2 = 1+2+4+8+16+ ... = ∞
Riemann Zeta function.


1/(1-x) |x=2 = -1
x
0
1
1+x+... |x=2 = 1+2+4+8+16+ ... = ∞
Riemann Zeta function.

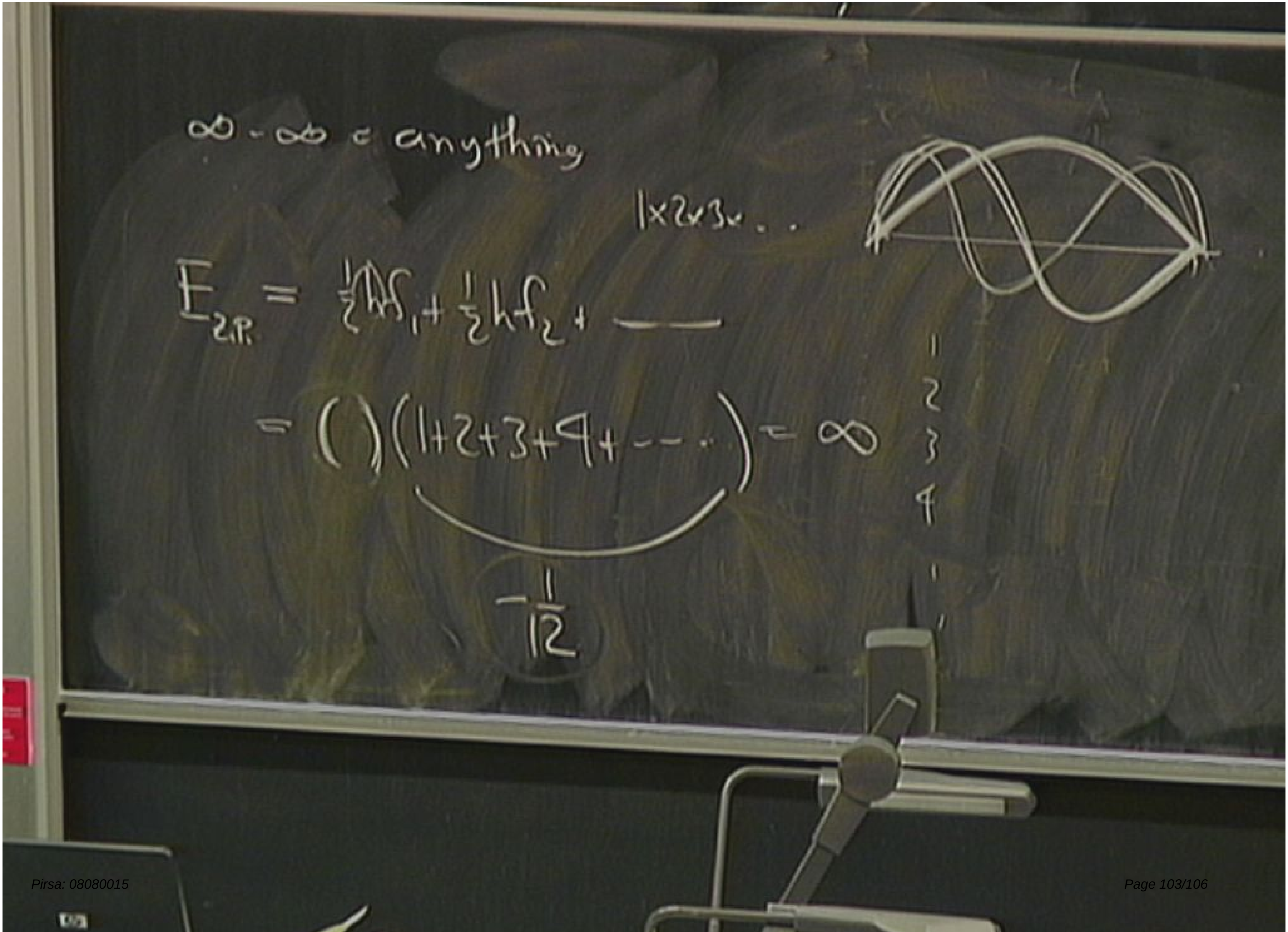

1/(1-x) | x=2 = -1
1+x+... | x=2 = 1+2+4+8+16+ ... = ∞
Riemann Zeta function.
ζ(z)
x+iy = z
y
x
0
1

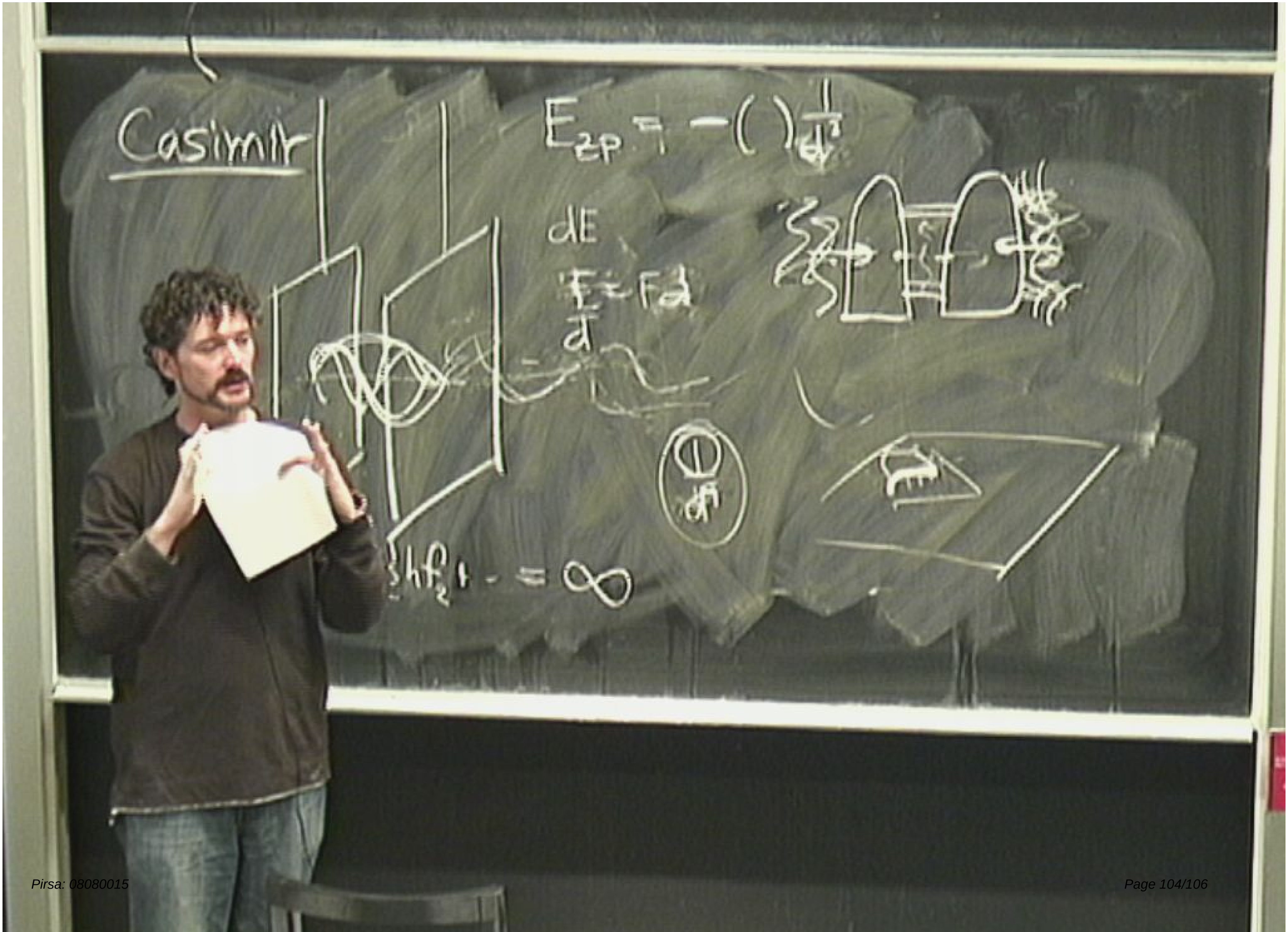


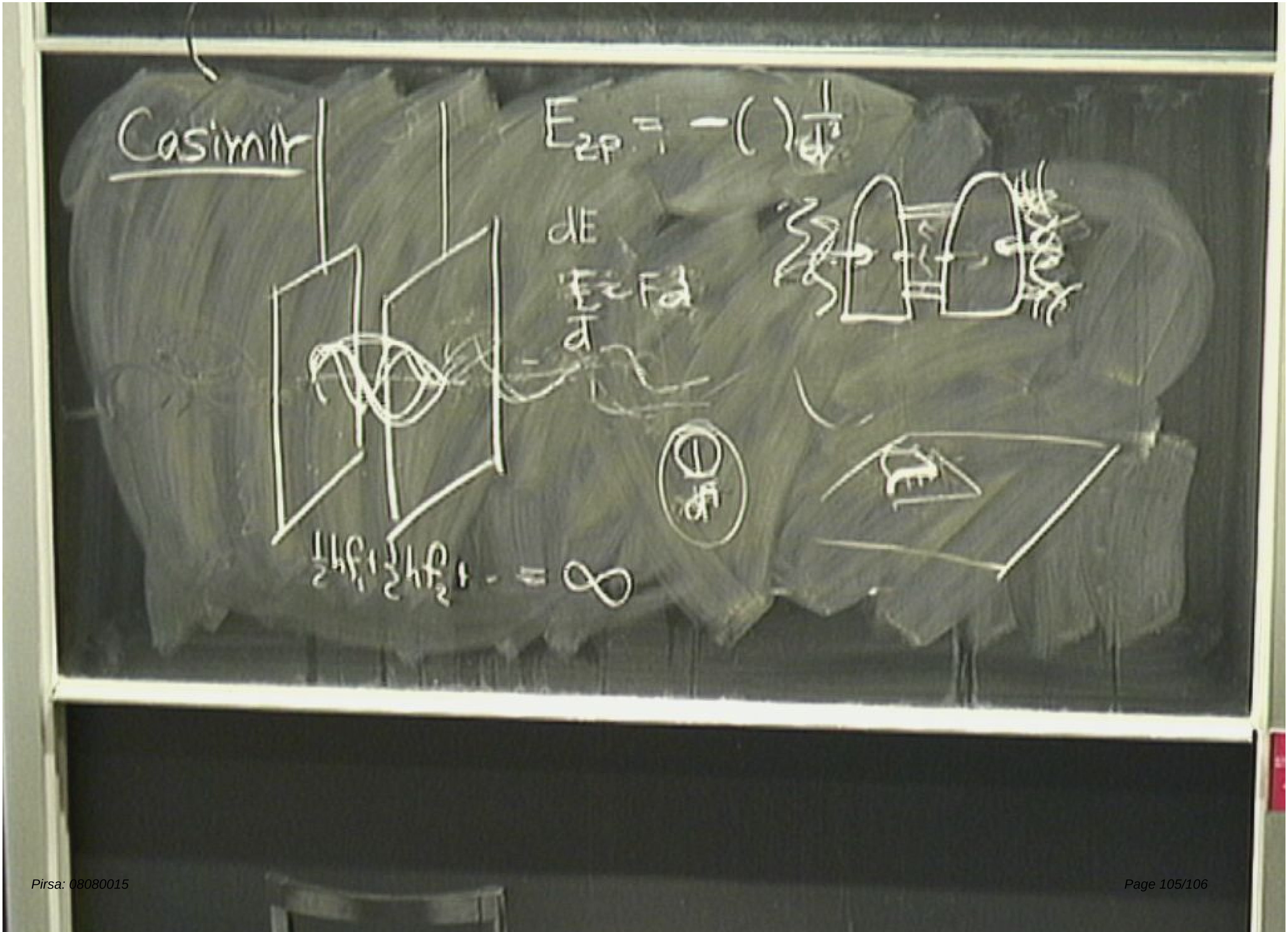
1/(1-x) | x=2 = -1
0
1
x
1+x+... | x=2 = 1+2+4+8+16+ ... = ∞
y
x+iy
=z
Riemann Zeta function.
ζ(z)
x
0
1

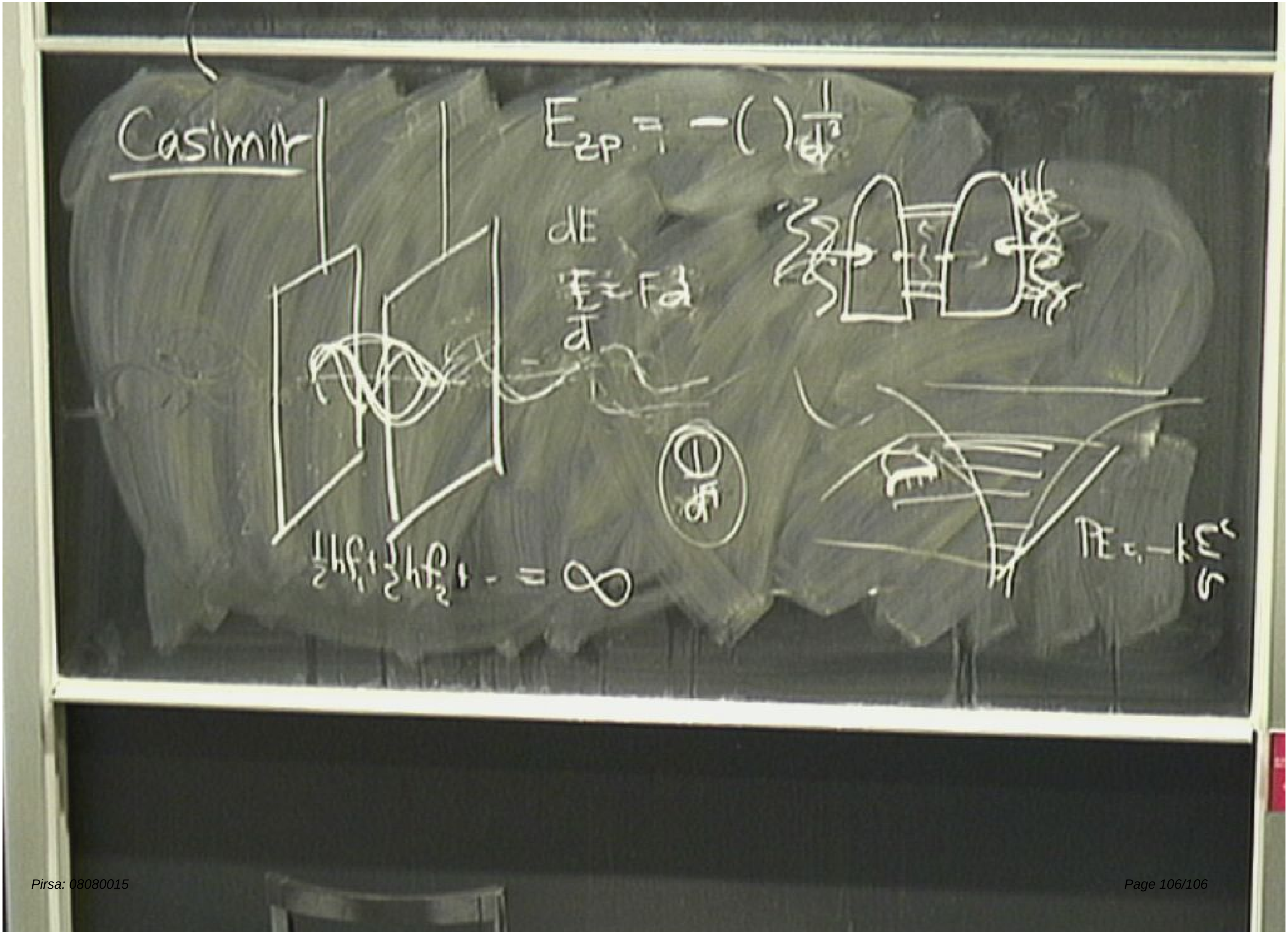


1/(1-x) | = -1
x=2
0 1 x
1+x+ ... | = 1+2+4+8+16+ ... = ∞
x=2
y
x+iy
=z
Riemann Zeta function.
ζ(z) =
0 1 x


∞ - ∞ = anything
1×2×3×...
$E_{2P} = \frac{1}{2}hf_1 + \frac{1}{2}hf_2 + \_\_\_\_$
$= (\ )(1+2+3+4+ \cdots) = \infty$
$-\frac{1}{12}$
1
2
3
4


Casimir


Casimir
$E_{ZP} = -(\ )\frac{1}{d^4}$
dE
E = Fd
$\frac{E}{d}$
$\frac{1}{2}hf_1 + \frac{1}{2}hf_2 + \dots = \infty$


Casimir
dE
½hf₁ + ½hf₂ + ... = ∞