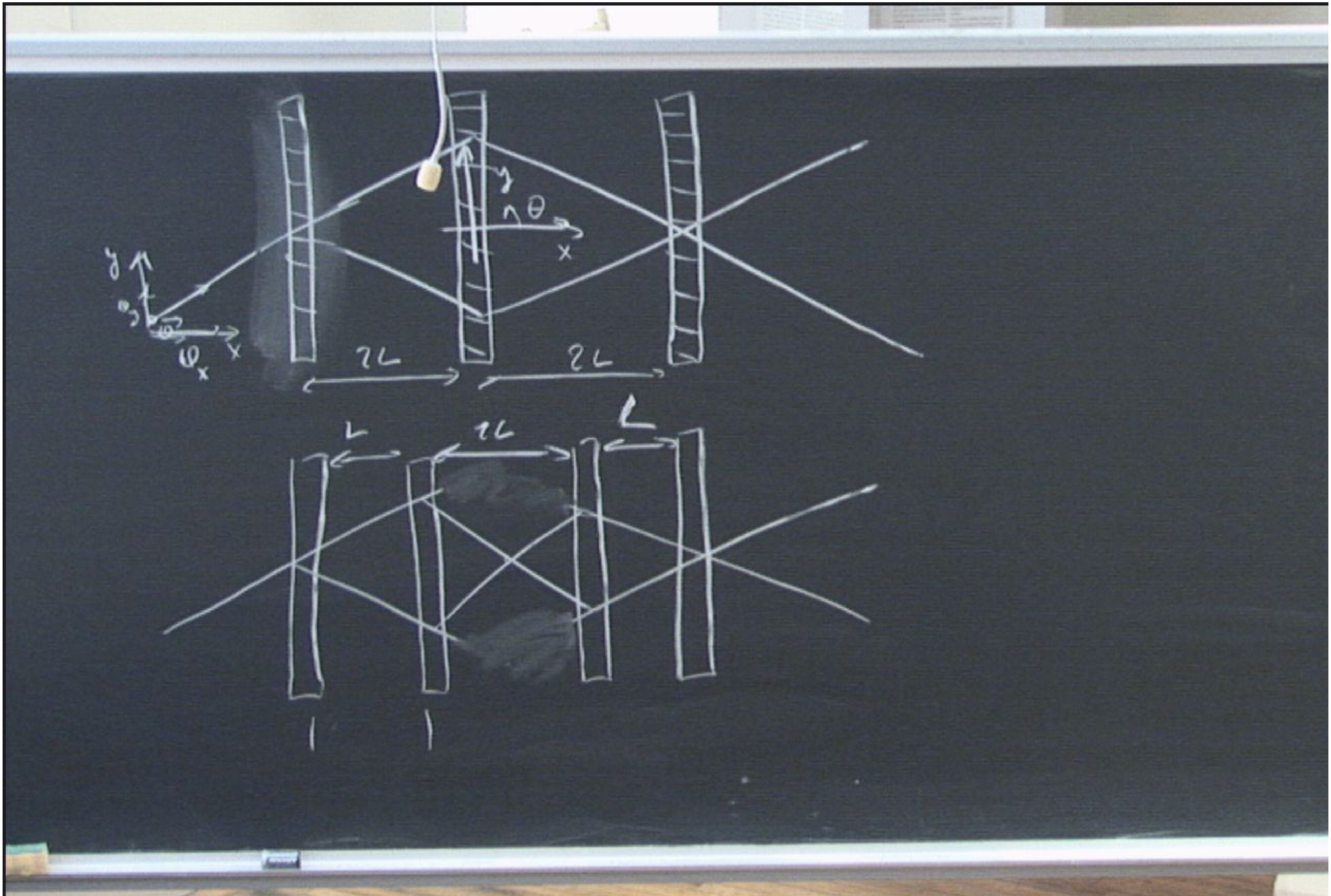
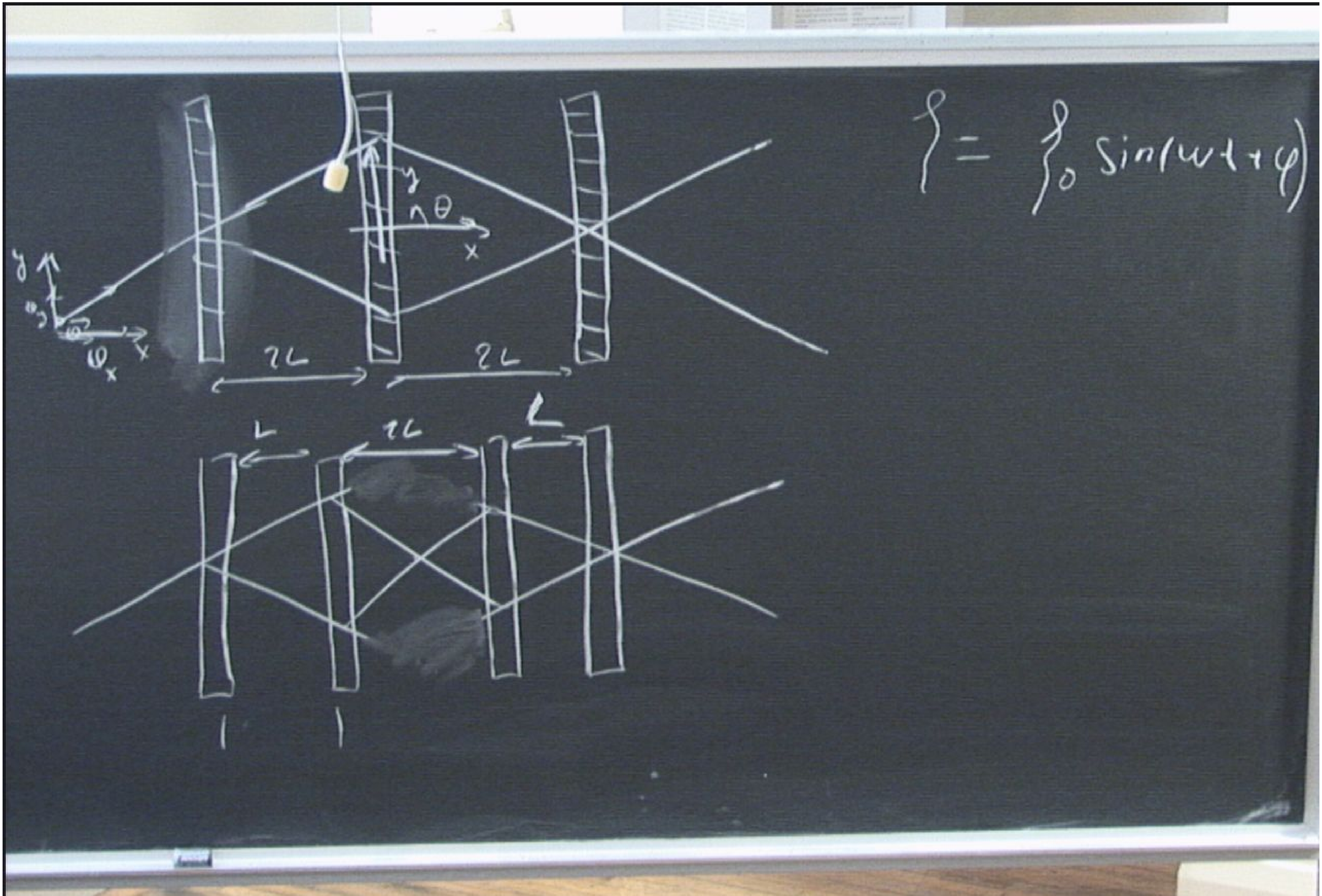
Title: Explorations in Quantum Info. (PHYS 641) - Lecture 8

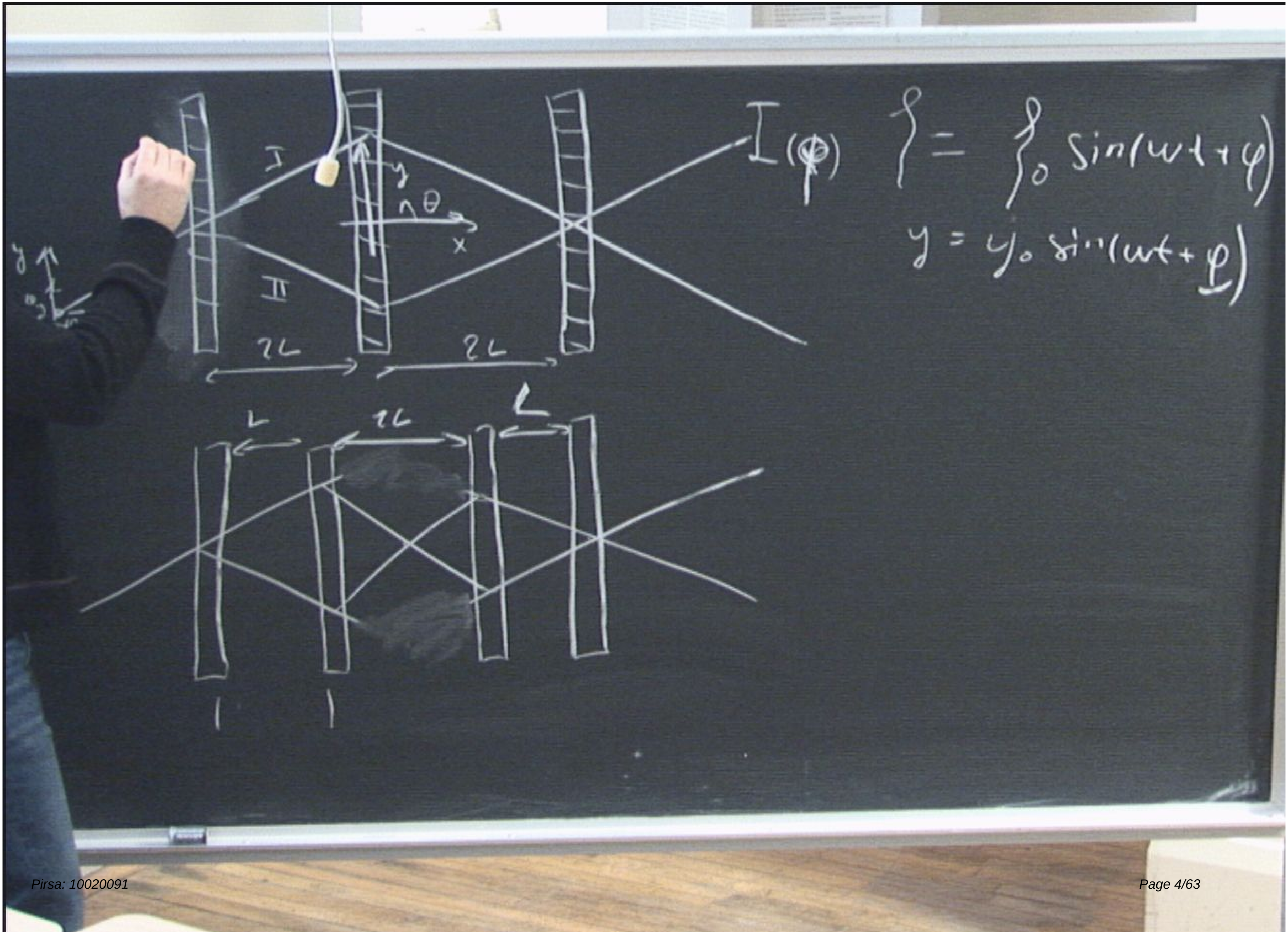
Date: Feb 25, 2010 09:00 AM

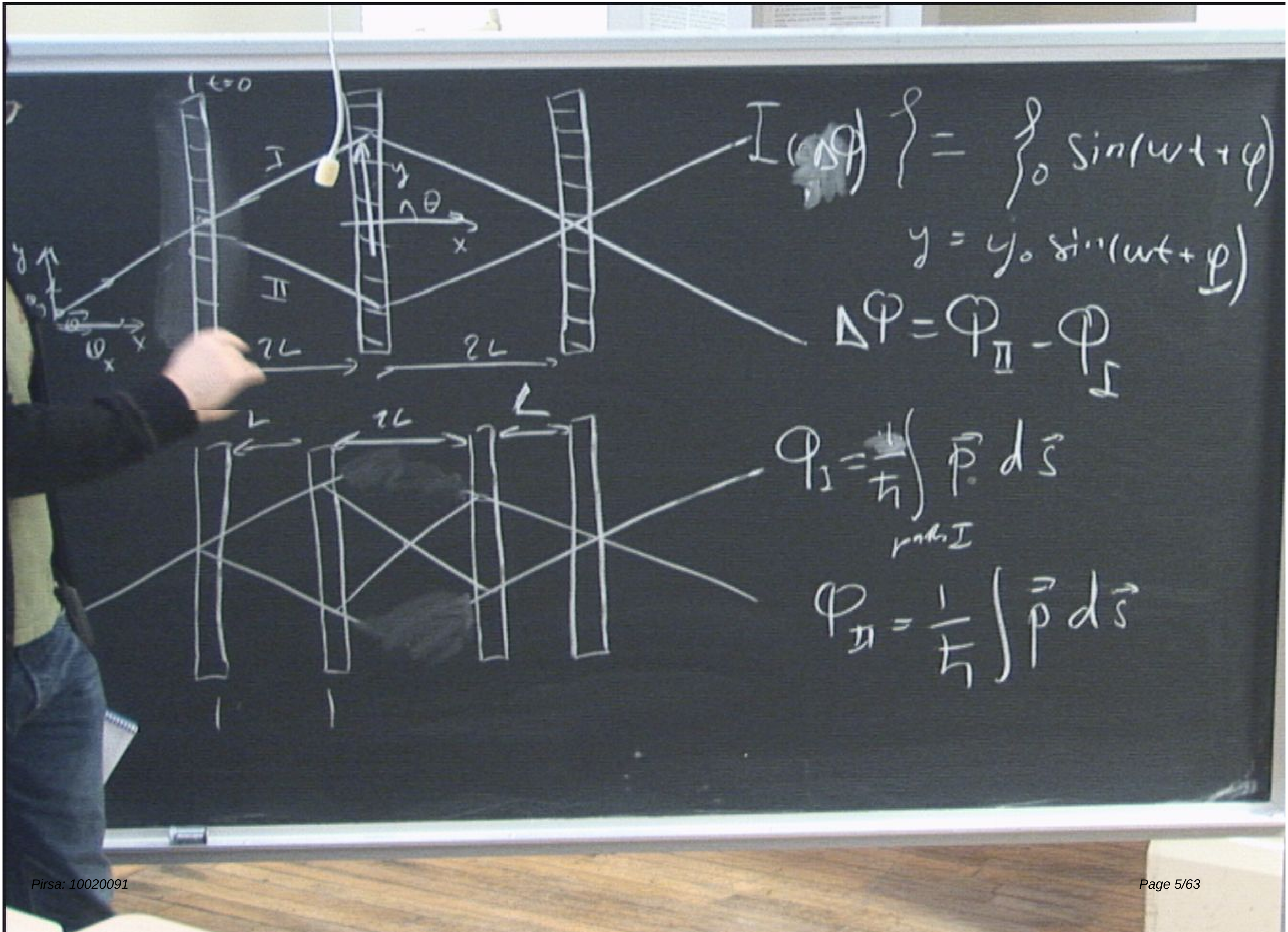
URL: http://pirsa.org/10020091

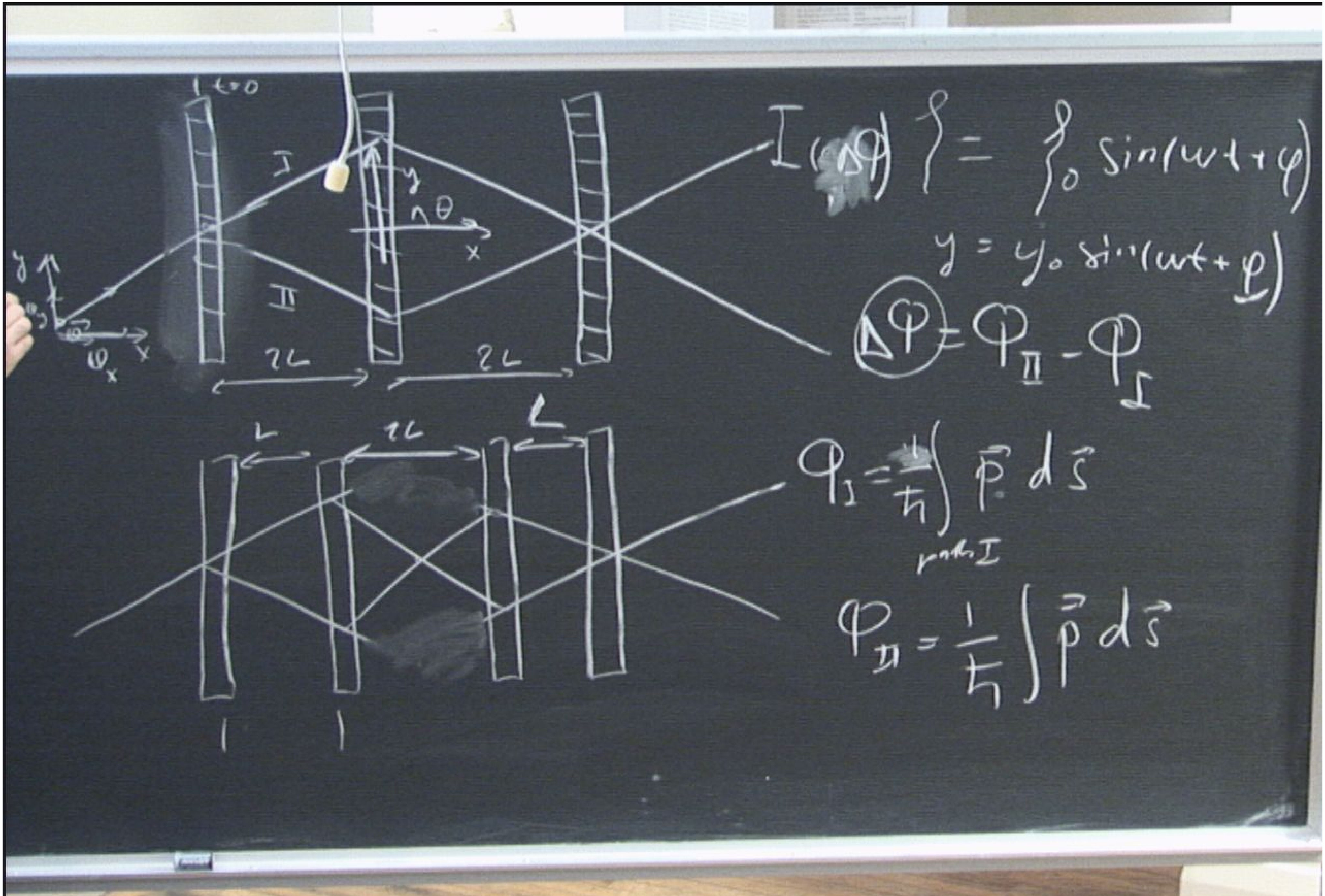
Abstract:

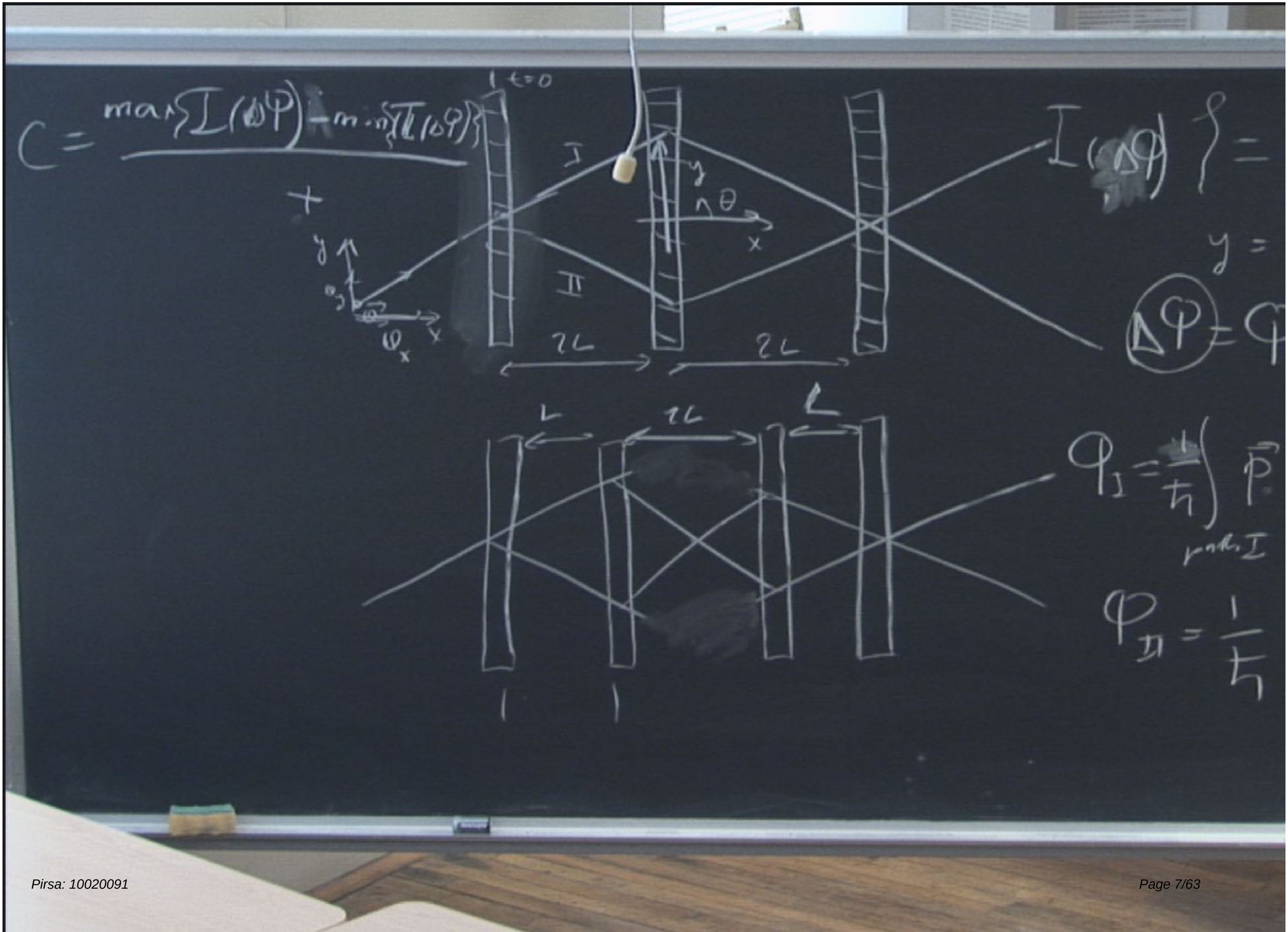

y
θ
x
y
x
2L
2L
L
2L
L

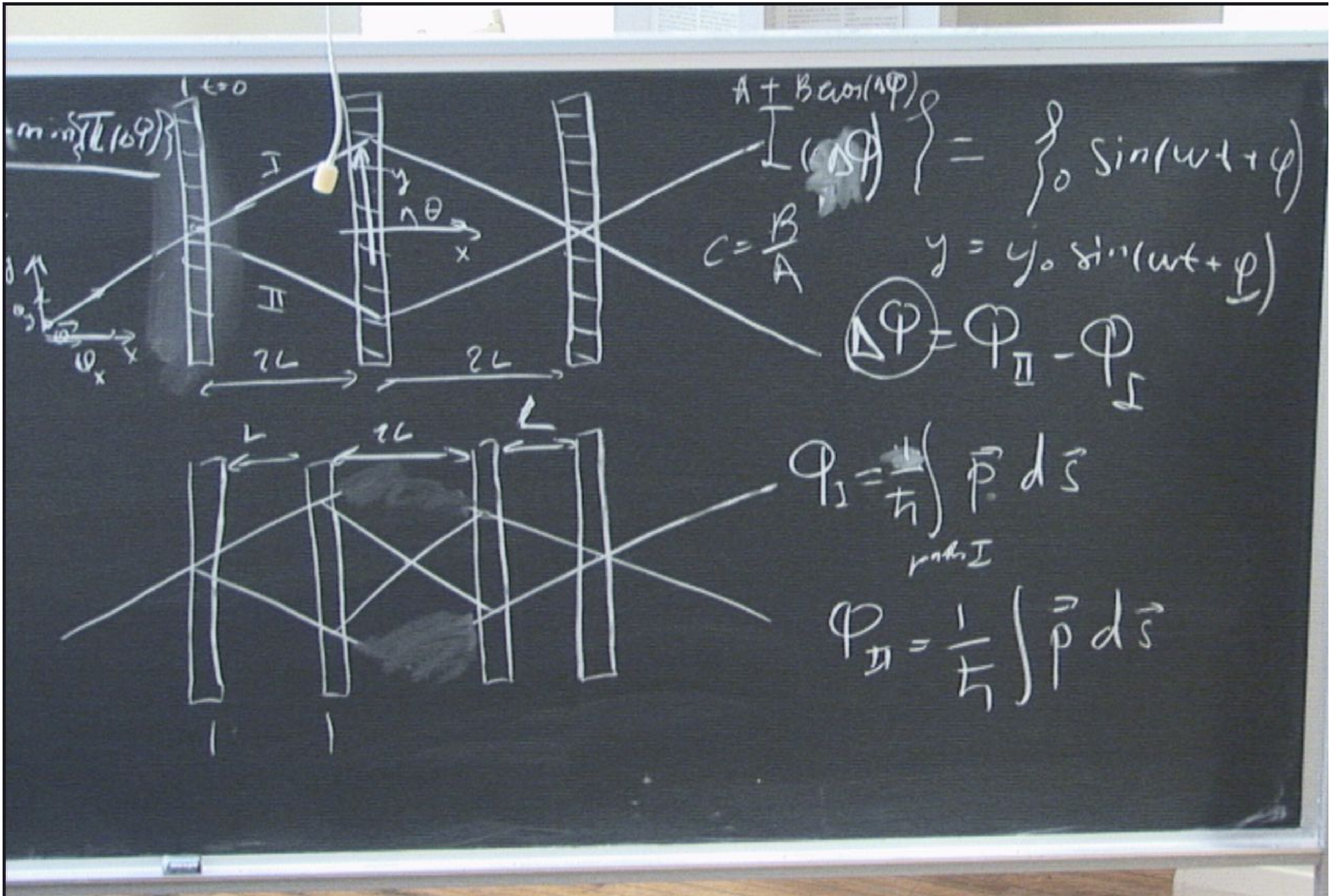

ρ = ρ₀ sin(ωt + φ)
y
x
θ
2L
2L
L
2L
L

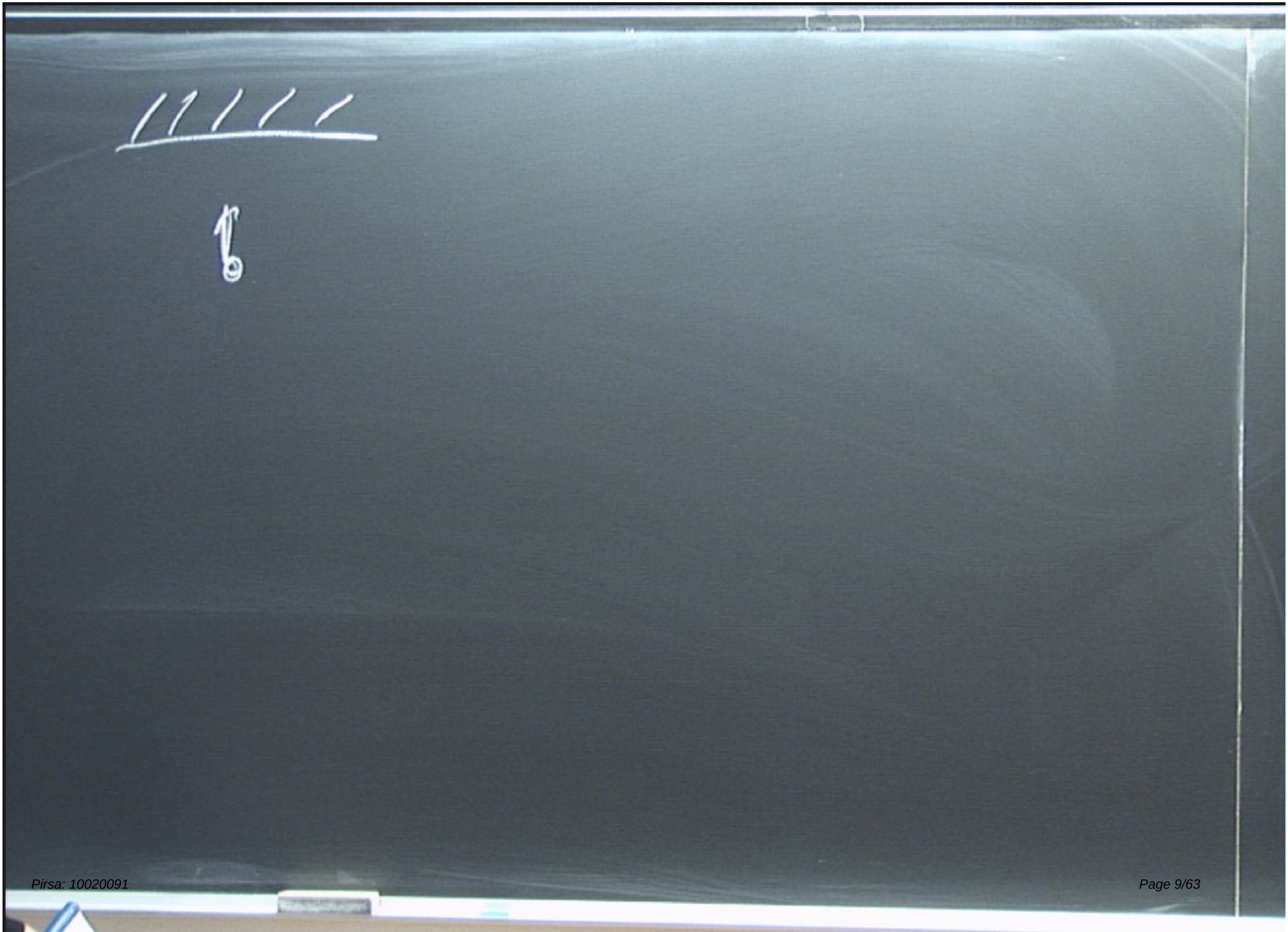

I
II
2L
2L
L
2L
L
x
y
θ
I(φ)
ξ = ξ0 sin(ωt + φ)
y = y0 sin(ωt + φ)

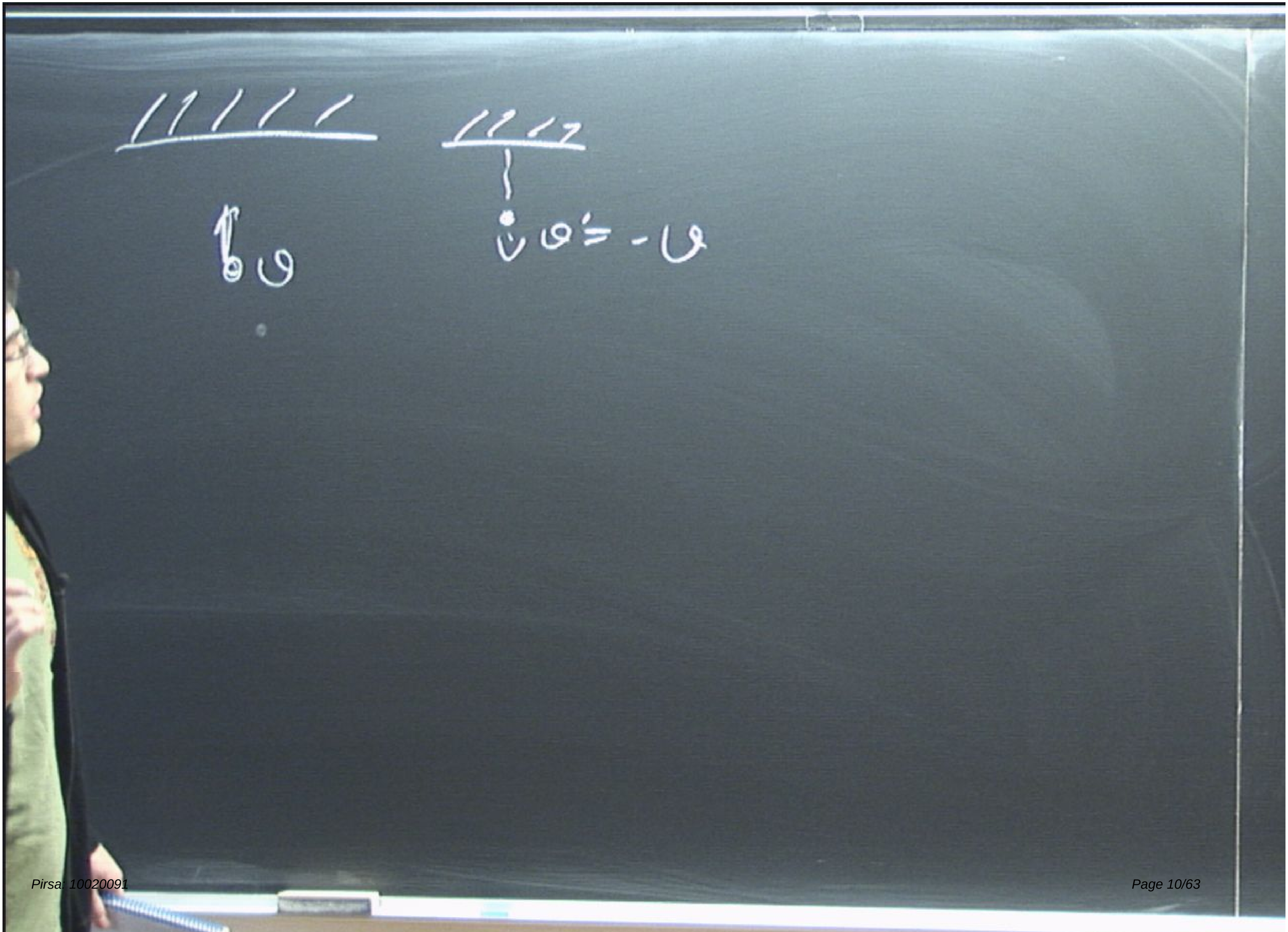

t=0
I
II
2L
2L
L
2L
L
y
x
θ
I(ΔΦ)
ξ = ξ₀ sin(ωt + φ)
y = y₀ sin(ωt + φ)
ΔΦ = Φ_II − Φ_I
Φ_I = 1/ħ ∫ p ds
path I
Φ_II = 1/ħ ∫ p ds

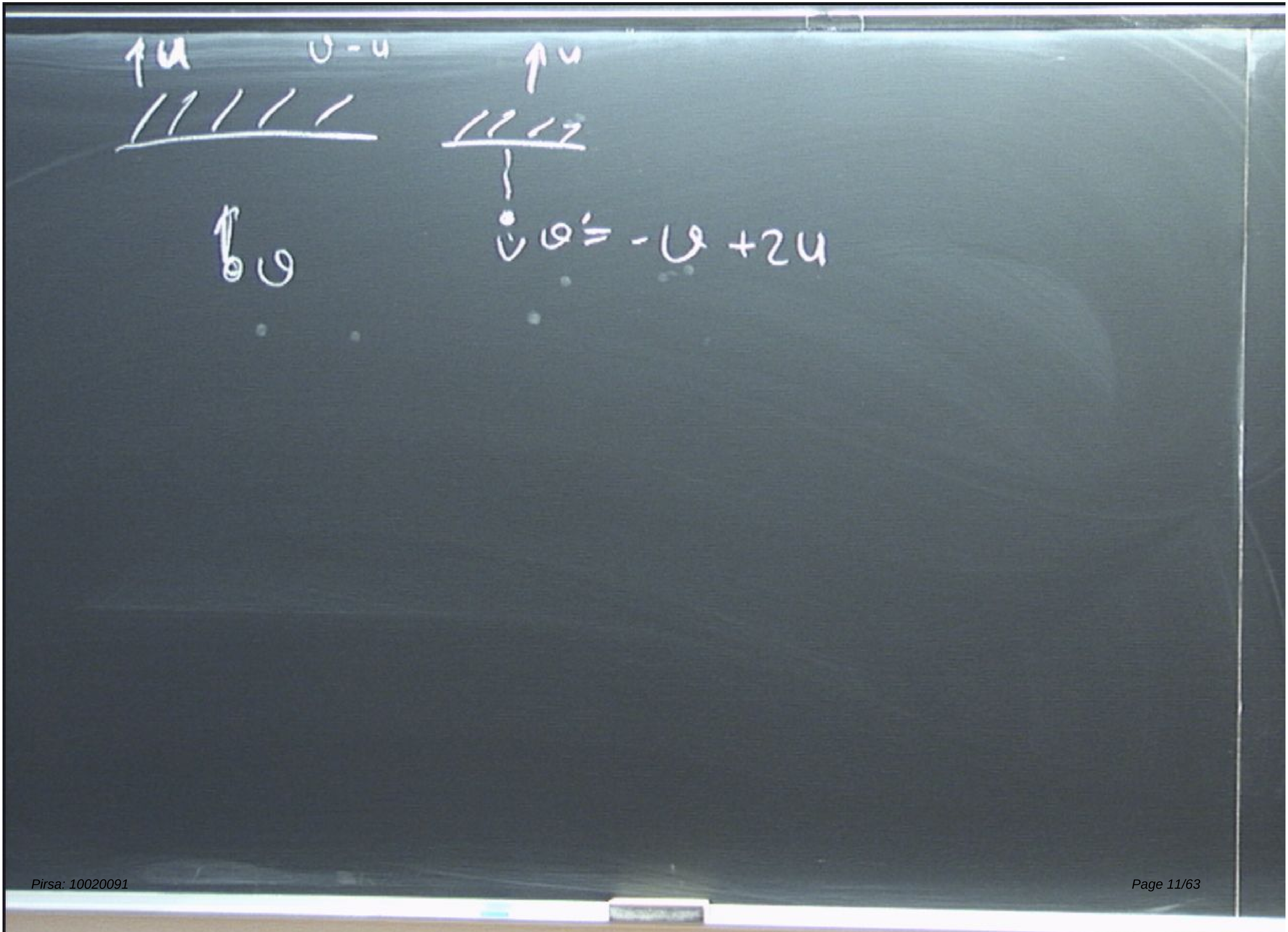

t=0
I
II
2L
2L
L
2L
L
y = y₀ sin(ωt + φ)
Δφ = φ_II − φ_I
path I

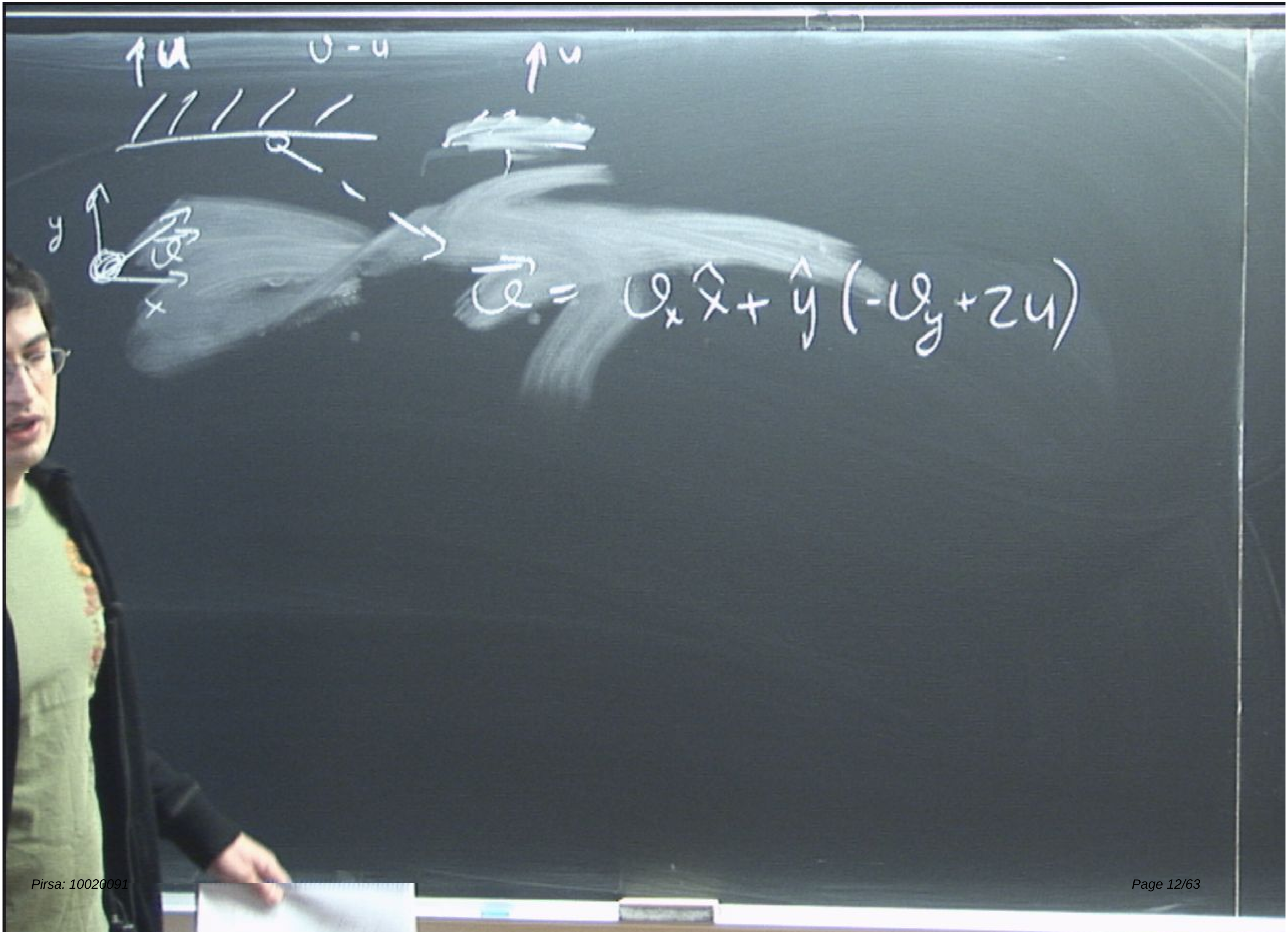

t=0
2L
2L
L
2L
L
path I


t=0
A ± B cos(ΔΦ)
I
II
2L
2L
L
2L
L
C = B/A
y = y0 sin(ωt + φ)
ΔΦ = ΦII − ΦI
ΦI = 1/ħ ∫ p ds
path I
ΦII = 1/ħ ∫ p ds



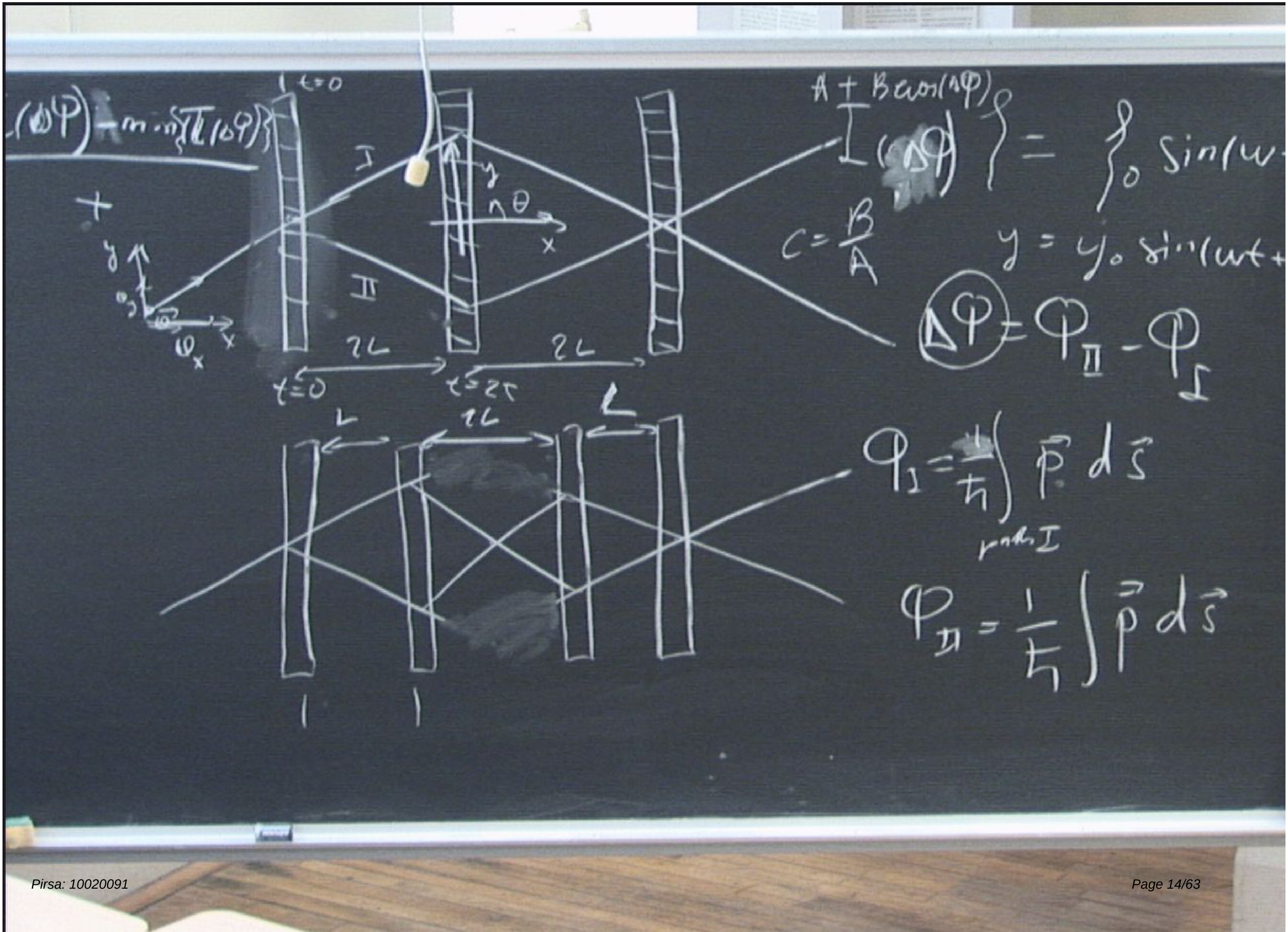


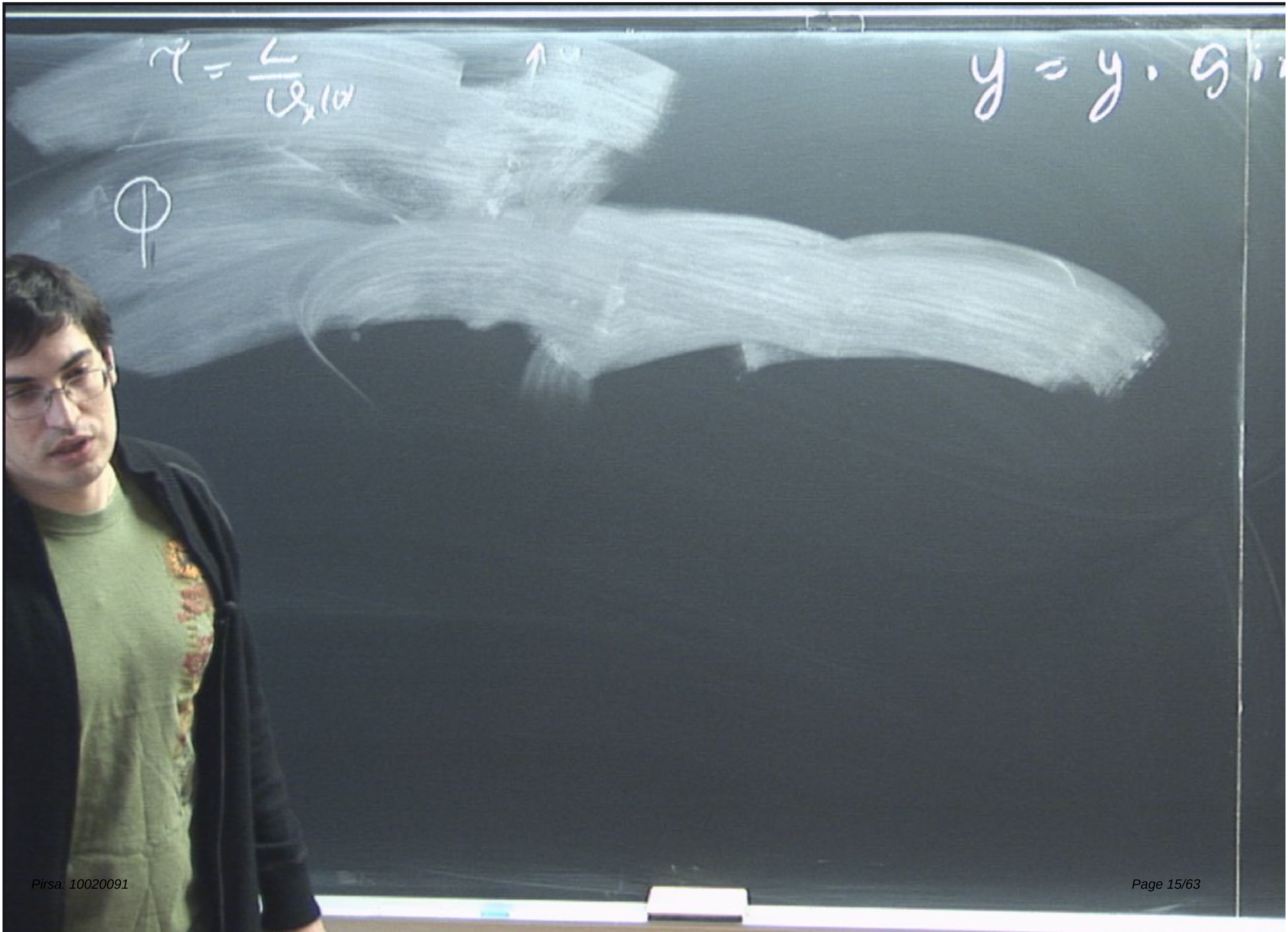

u
v - u
u
v
v' = -v + 2u

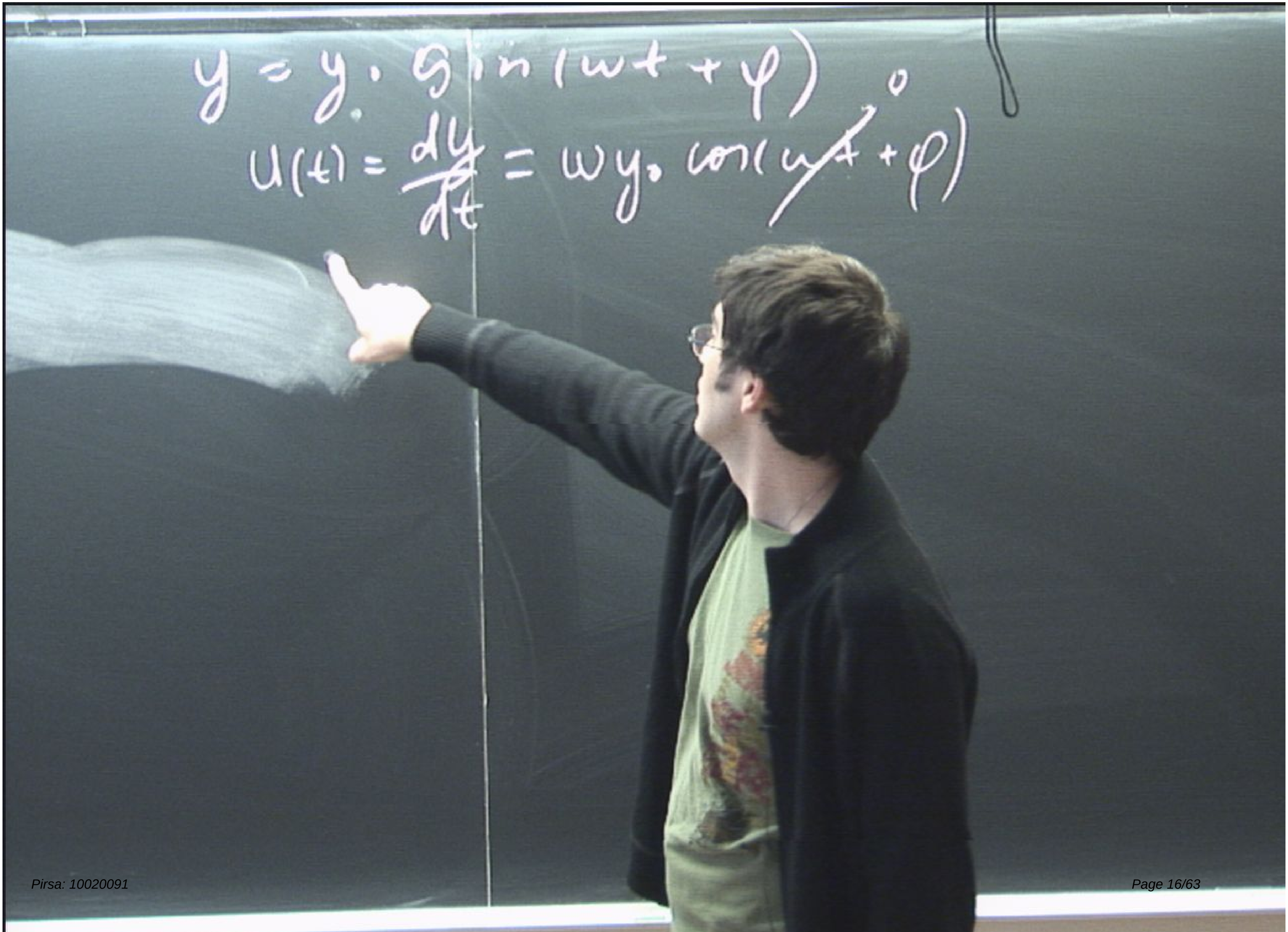


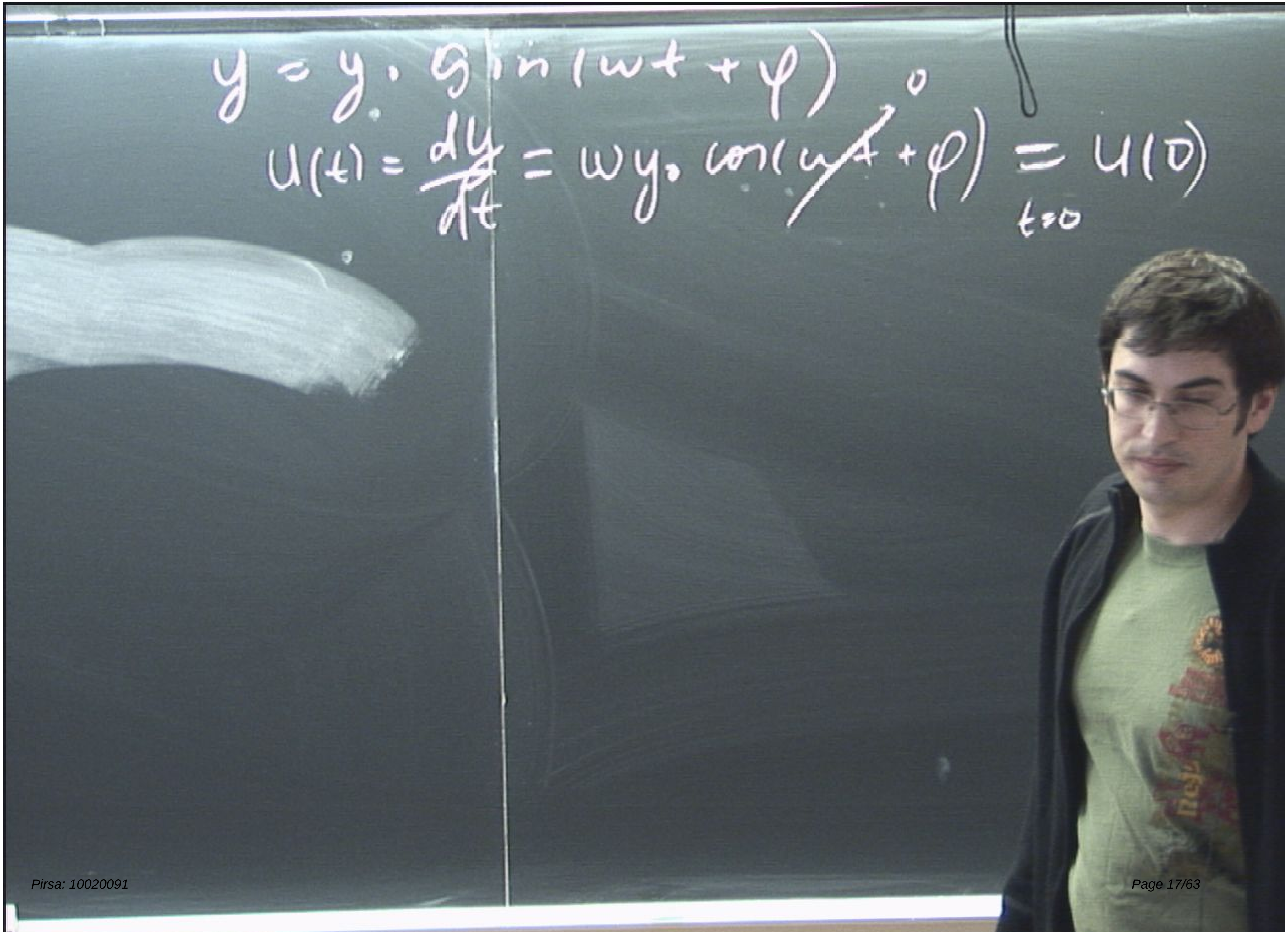
u
v - u
u
y
x
v = v_x x̂ + ŷ (-v_y + 2u)

$$y = y_0 \sin(\omega t + \varphi)$$


t=0
2L
2L
t=0
L
2L
L
C = B/A
A ± B cos(ΔΦ)
ΔΦ = Φ_II − Φ_I
path I

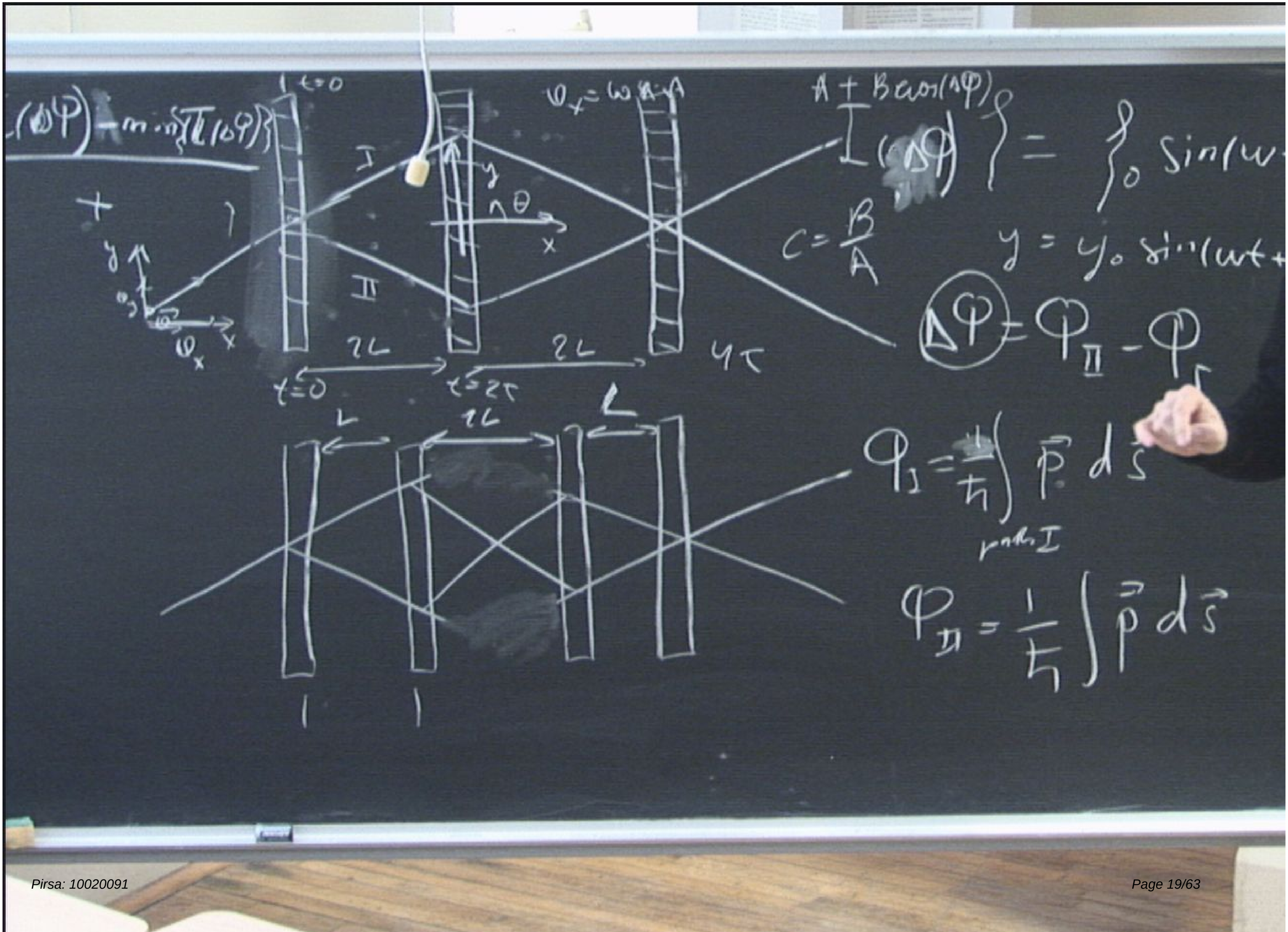



y = y0 sin(ωt + φ)
U(t) = dy/dt = ω y0 cos(ωt + φ)

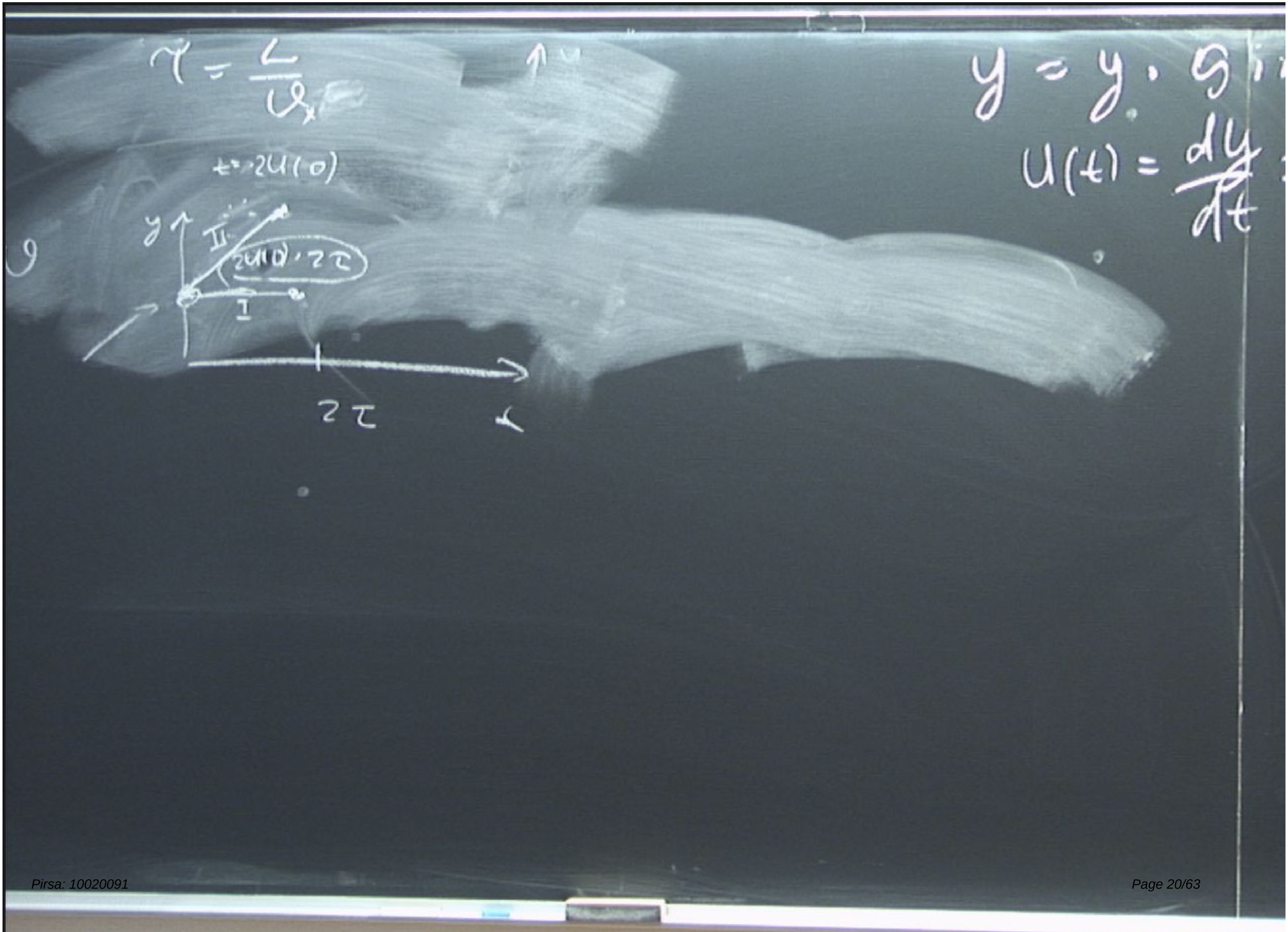


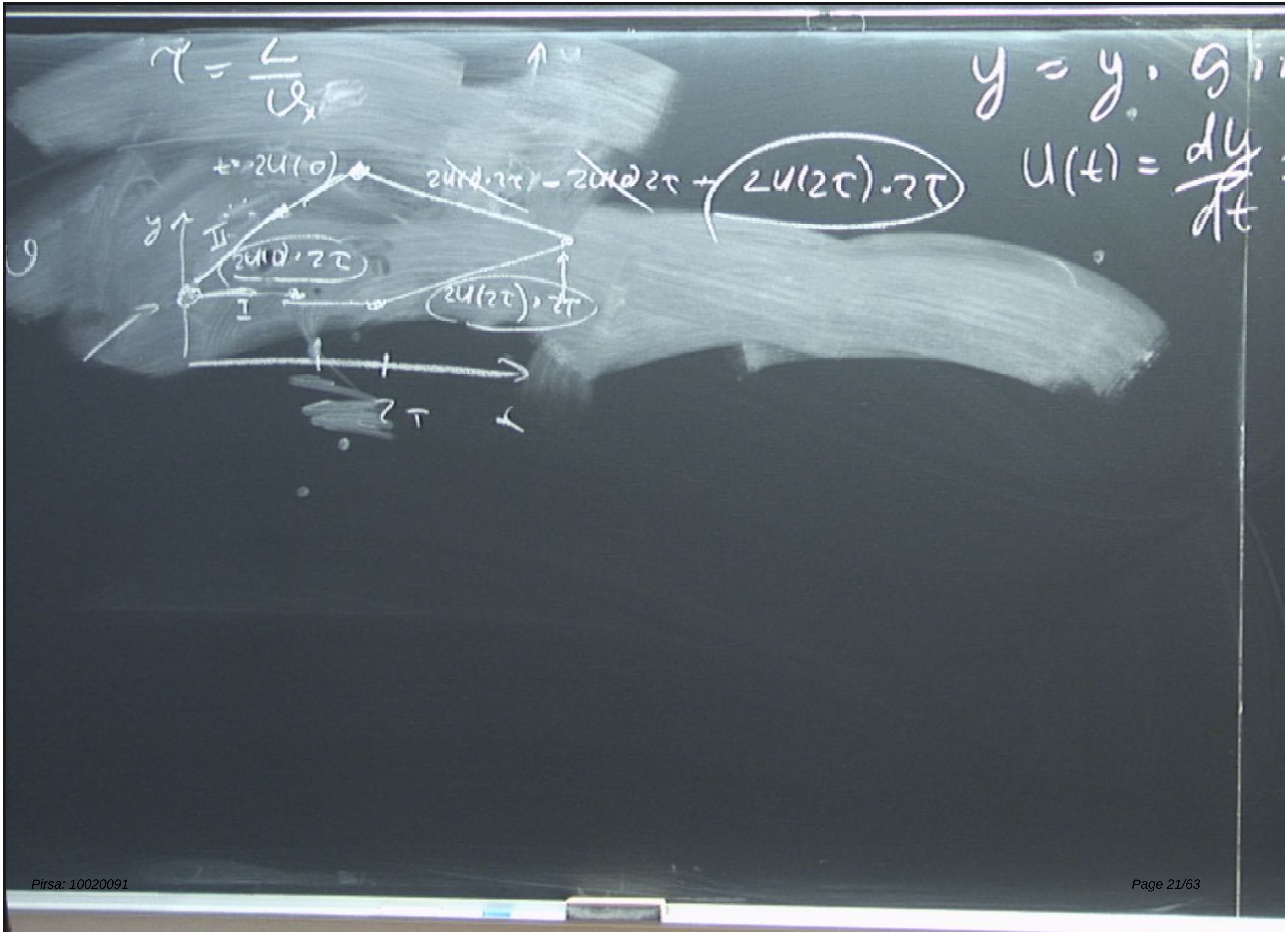
$y = y_0 \sin(\omega t + \varphi)$
$u(t) = \frac{dy}{dt} = \omega y_0 \cos(\omega t + \varphi) \underset{t=0}{=} u(0)$

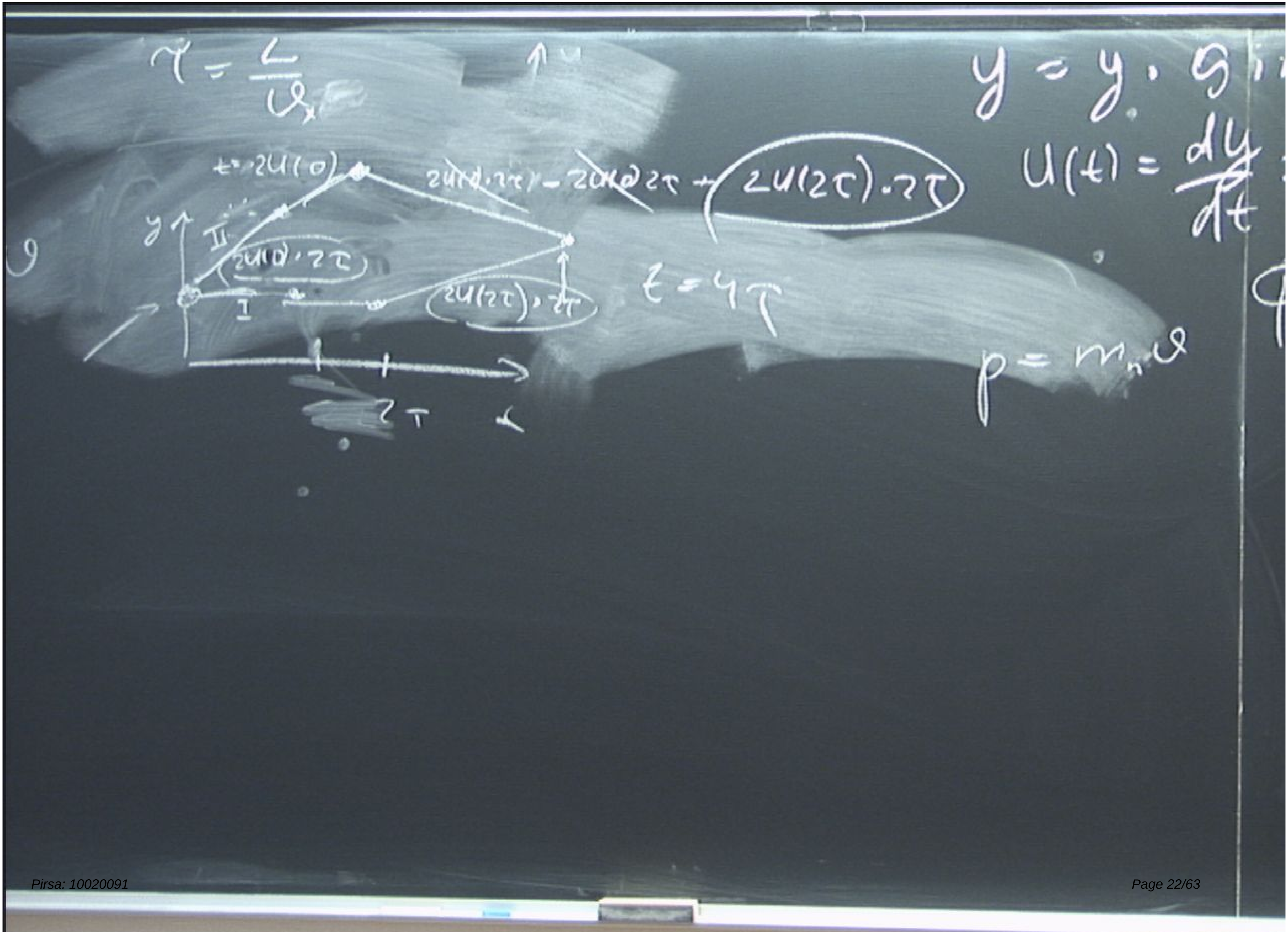

U(t) = dy/dt



t=0
I
II
2L
2L
t=0
t=2τ
4τ
L
2L
L
A ± B cos(nΦ)
C = B/A
y = y₀ sin(ωt+
ΔΦ = Φ_II − Φ_I
Φ_I = 1/ħ ∫ p ds
path I
Φ_II = 1/ħ ∫ p ds


τ = L / v_x
t=2U(0)
2U(0)·2τ
2τ
U(t) = dy/dt


τ = L / v_x
y = y · g
U(t) = dy/dt
2U(2τ)·2τ
2U(0)·2τ
y
I
II
2τ


τ = L / v_x
y = y₀ · g
U(t) = dy/dt
2U(2τ)·2τ
2U(0)·2τ
2U(2τ)·2τ
t = 4τ
p = m₀v
2τ
I
II

$$y = y_0 \sin(\omega t + \varphi)$$

$$(2\tau) \cdot 2\tau$$

$$u(t) = \frac{dy}{dt} = \omega y_0 \cos(\omega t + \varphi) \underset{t=0}{=} u(0)$$

$$p = m_n v$$

$$\varphi_I = \frac{m_n}{\hbar}$$

$$y = y_0 \sin(\omega t + \varphi)$$

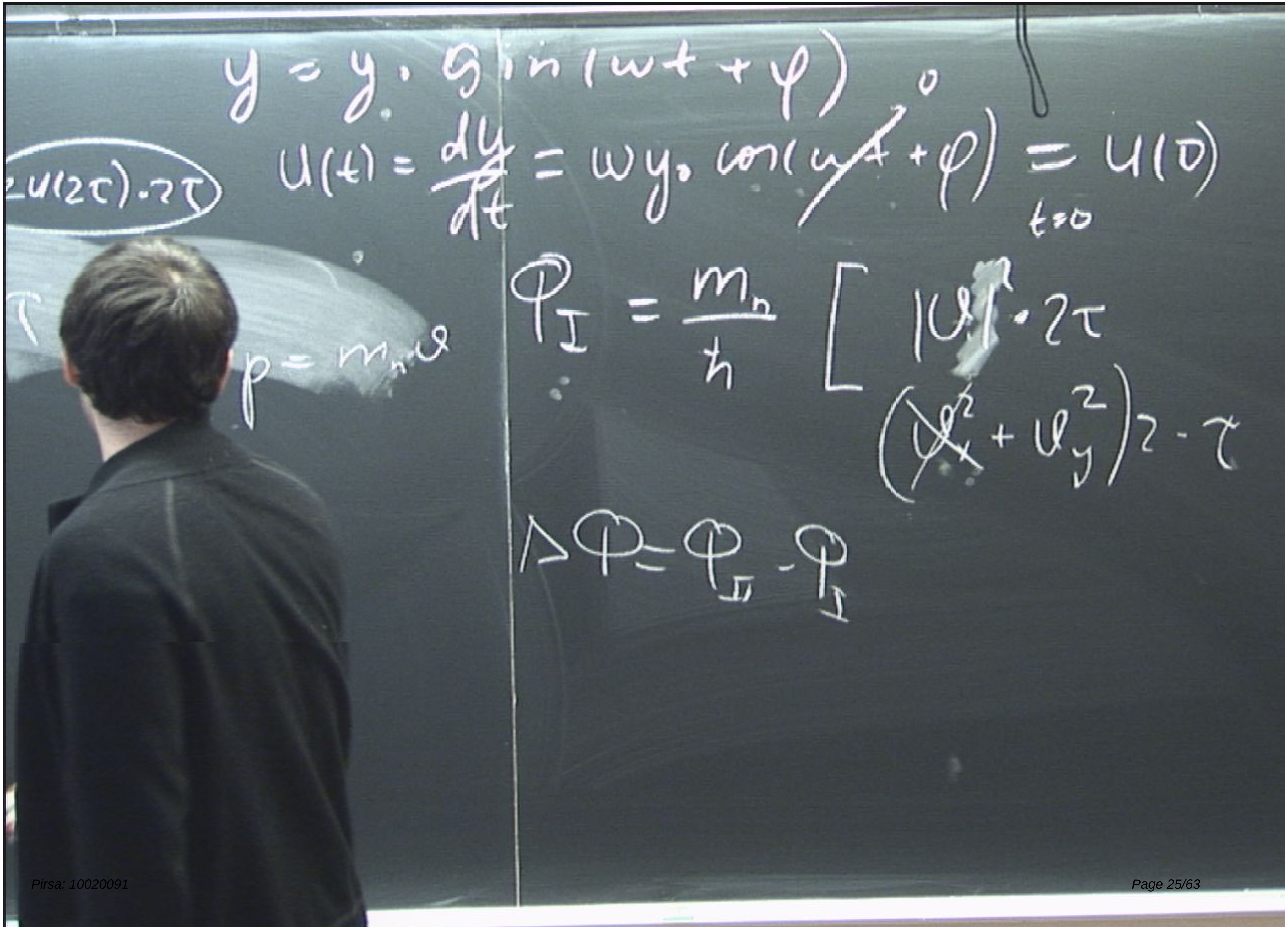
$$u(2\tau)\cdot 2\tau$$

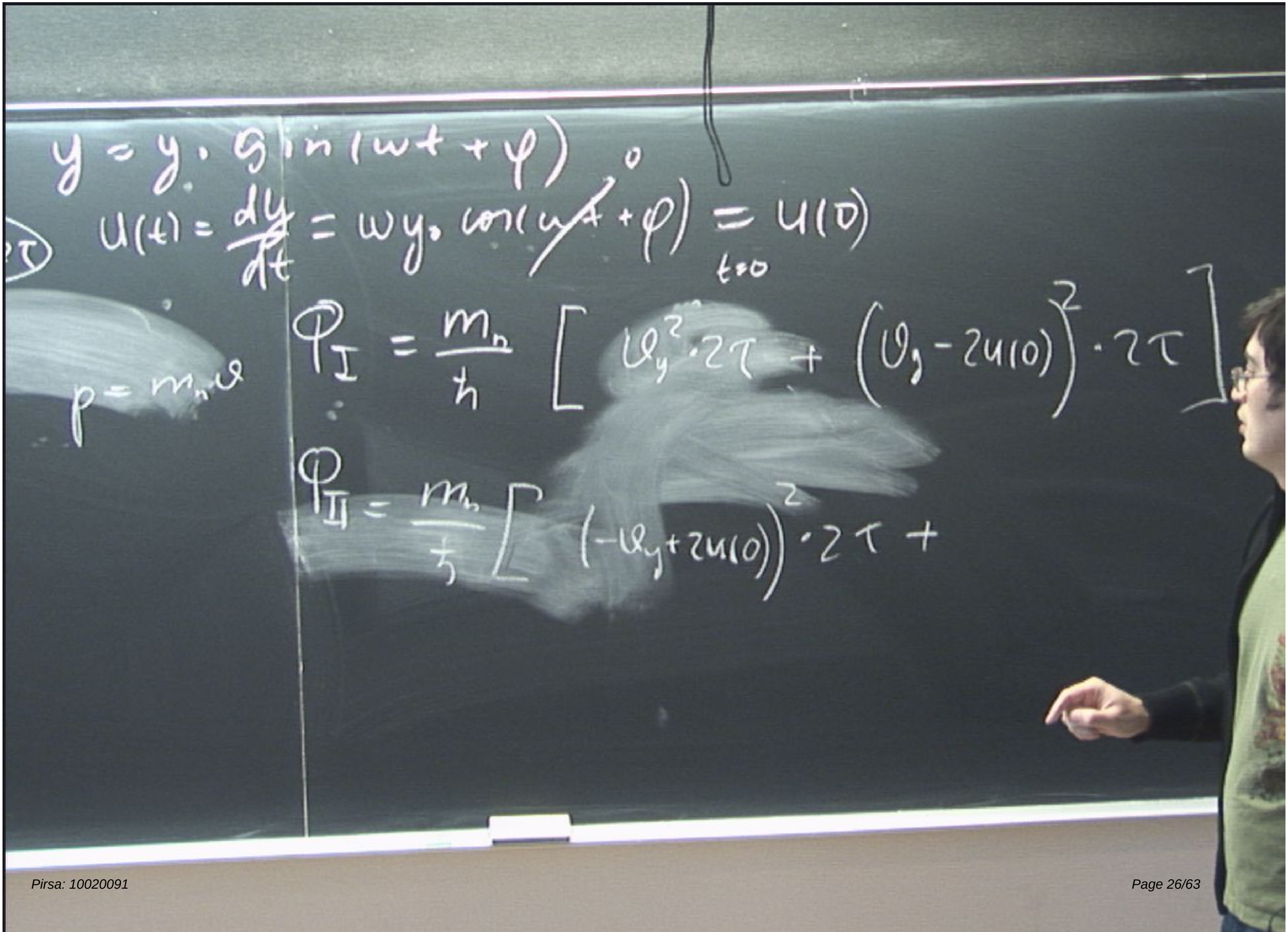
$$u(t) = \frac{dy}{dt} = \omega y_0 \cos(\omega t + \varphi) \underset{t=0}{=} u(0)$$

$$p = m_n v$$

$$\varphi_I = \frac{m_n}{\hbar}\left[\, |v|^2 \cdot 2\tau \right.$$

$$(v_x^2 + v_y^2)\, 2 \cdot \tau$$


y = y₀ sin(ωt + φ)
u(t) = dy/dt = ωy₀ cos(ωt + φ) = u(0)
t=0
p = mₙv
φ_I = mₙ/ħ [|v|² · 2τ
(v_x² + v_y²) 2 · τ
Δφ = φ_II − φ_I


y = y₀ sin(ωt + φ)
u(t) = dy/dt = ωy₀ cos(ωt + φ) = u(0)
t=0
p = mₙv
φ_I = mₙ/ħ [v_y²·2τ + (v_y − 2u(0))²·2τ]
φ_II = mₙ/ħ [(−v_y + 2u(0))²·2τ +

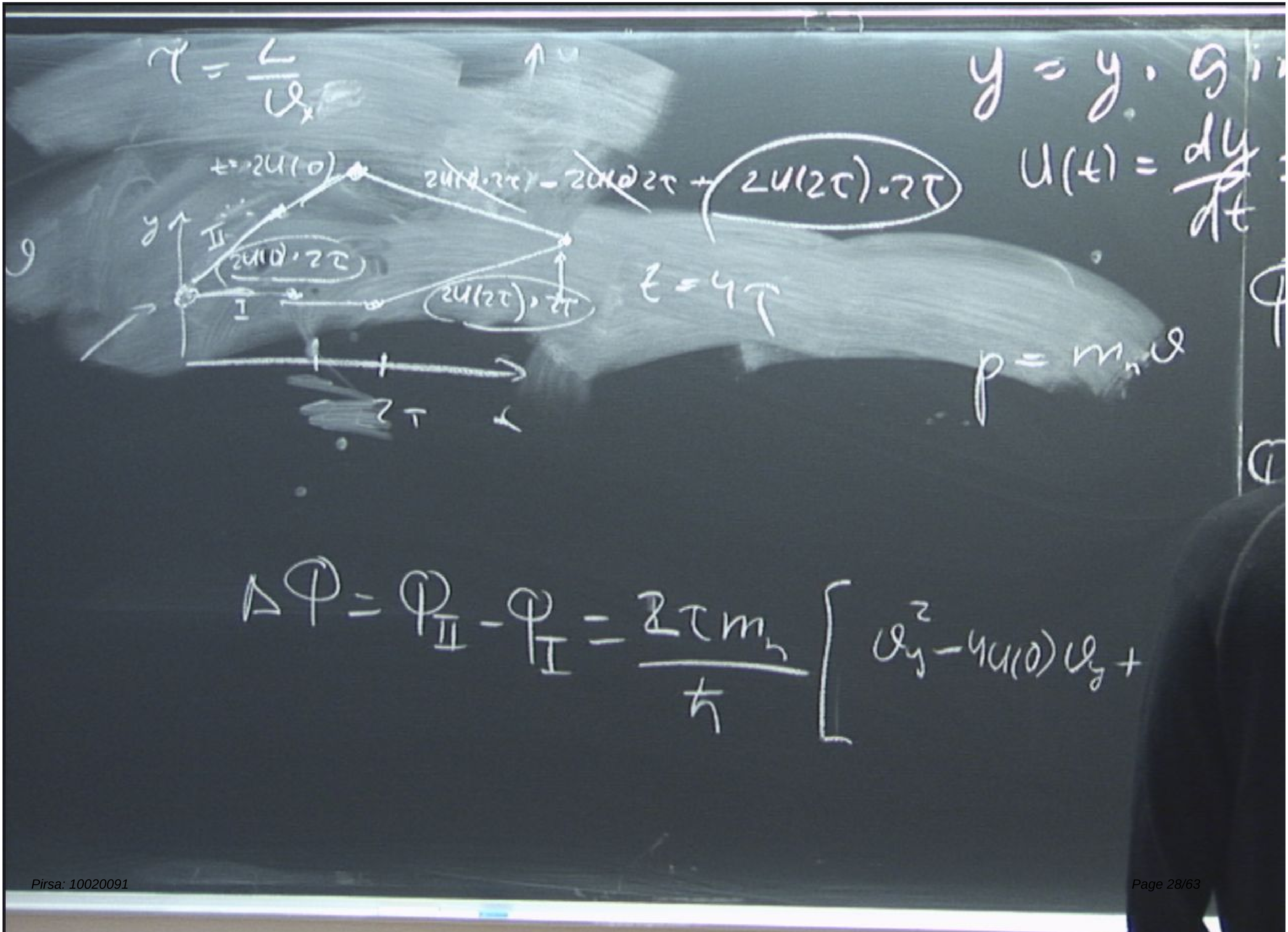
$$y = y_0 \sin(\omega t + \varphi)$$

$$u(t) = \frac{dy}{dt} = \omega y_0 \cos(\omega t + \varphi)\Big|_{t=0} = u(0)$$

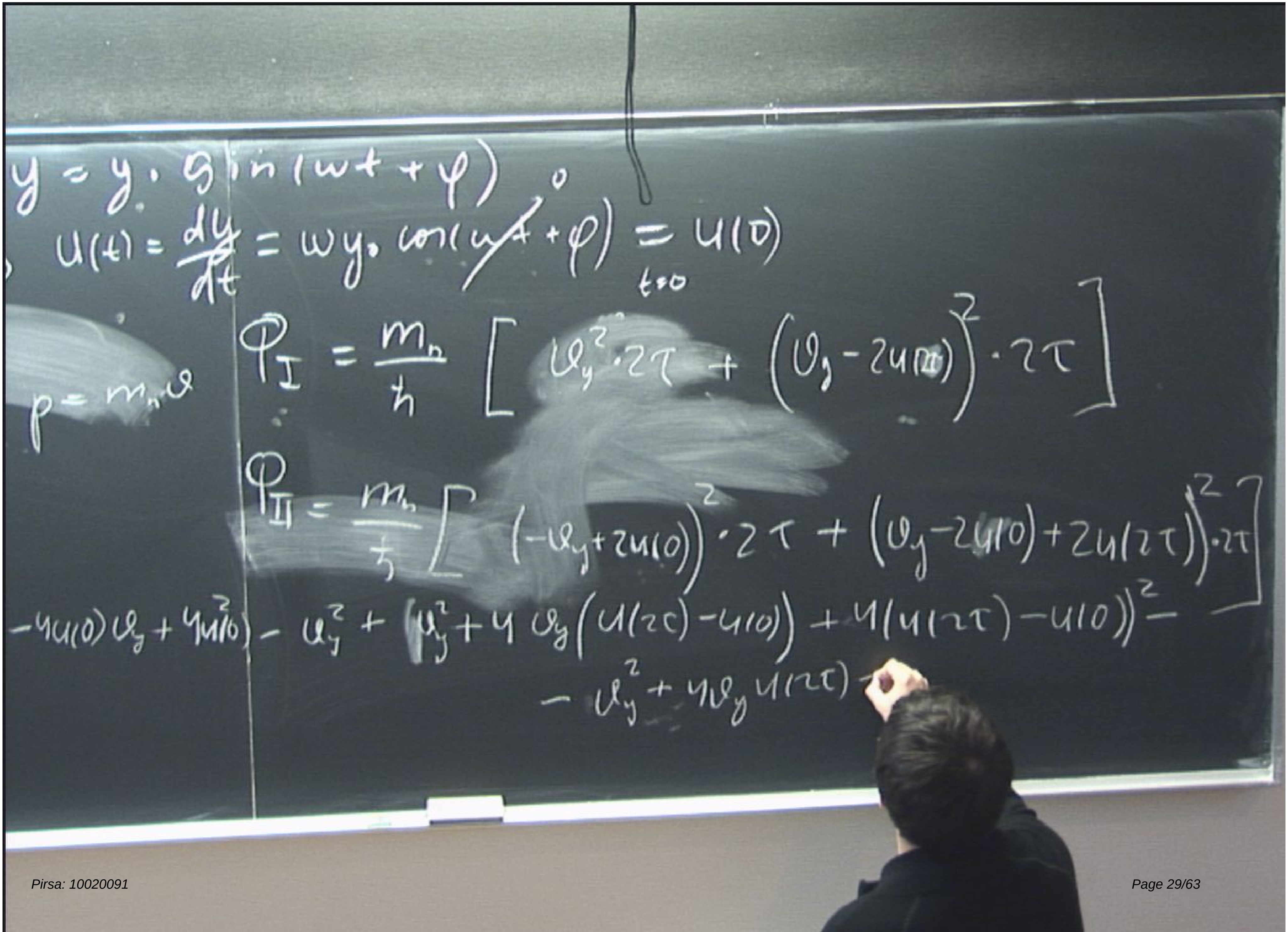
$$p = m_n \vartheta$$

$$\varphi_I = \frac{m_n}{\hbar}\left[\vartheta_y^2 \cdot 2\tau + \left(\vartheta_y - 2u(0)\right)^2 \cdot 2\tau \right]$$

$$\varphi_{II} = \frac{m_n}{\hbar}\left[\left(-\vartheta_y + 2u(0)\right)^2 \cdot 2\tau + \left(\vartheta_y - 2u(0) + 2u(2\tau)\right)^2 \cdot 2\tau \right]$$



τ = L / v_x
t = 2u(0)
2u(0)·2τ − 2u(0)2τ + 2u(2τ)·2τ
y
II
2u(0)·2τ
I
2u(2τ)·2τ
t = 4τ
2τ
y = y·g
u(t) = dy/dt
p = m_n v
ΔΦ = Φ_II − Φ_I = (2τ m_n / ħ) [v_y² − 4u(0) v_y +


$y = y_0 \sin(\omega t + \varphi)$
$u(t) = \frac{dy}{dt} = \omega y_0 \cos(\omega t + \varphi) \underset{t=0}{=} u(0)$
$p = m_n v$
$\varphi_I = \frac{m_n}{\hbar} \left[v_y^2 \cdot 2\tau + (v_y - 2u(0))^2 \cdot 2\tau \right]$
$\varphi_{II} = \frac{m_n}{\hbar} \left[(-v_y + 2u(0))^2 \cdot 2\tau + (v_y - 2u(0) + 2u(2\tau))^2 \cdot 2\tau \right]$
$-4u(0)v_y + 4u^2(0)) - v_y^2 + (v_y^2 + 4v_y(u(2\tau) - u(0)) + 4(u(2\tau) - u(0))^2 -$
$- v_y^2 + 4v_y u(2\tau)$

$$y = y_0 \sin(\omega t + \varphi)$$

$$u(t) = \frac{dy}{dt} = \omega y_0 \cos(\omega t + \varphi) \underset{t=0}{=} u(0)$$

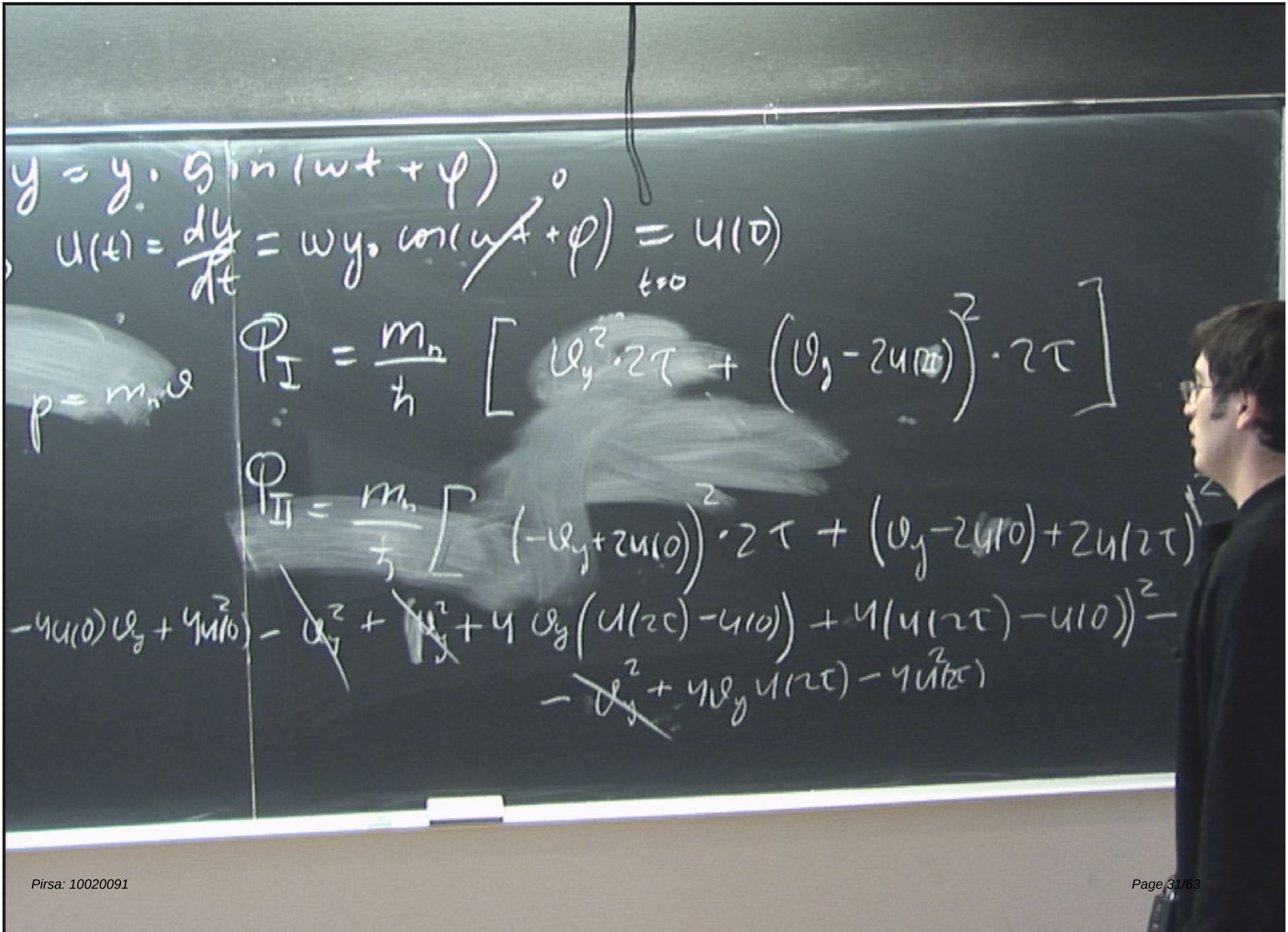
$$p = m_n v$$

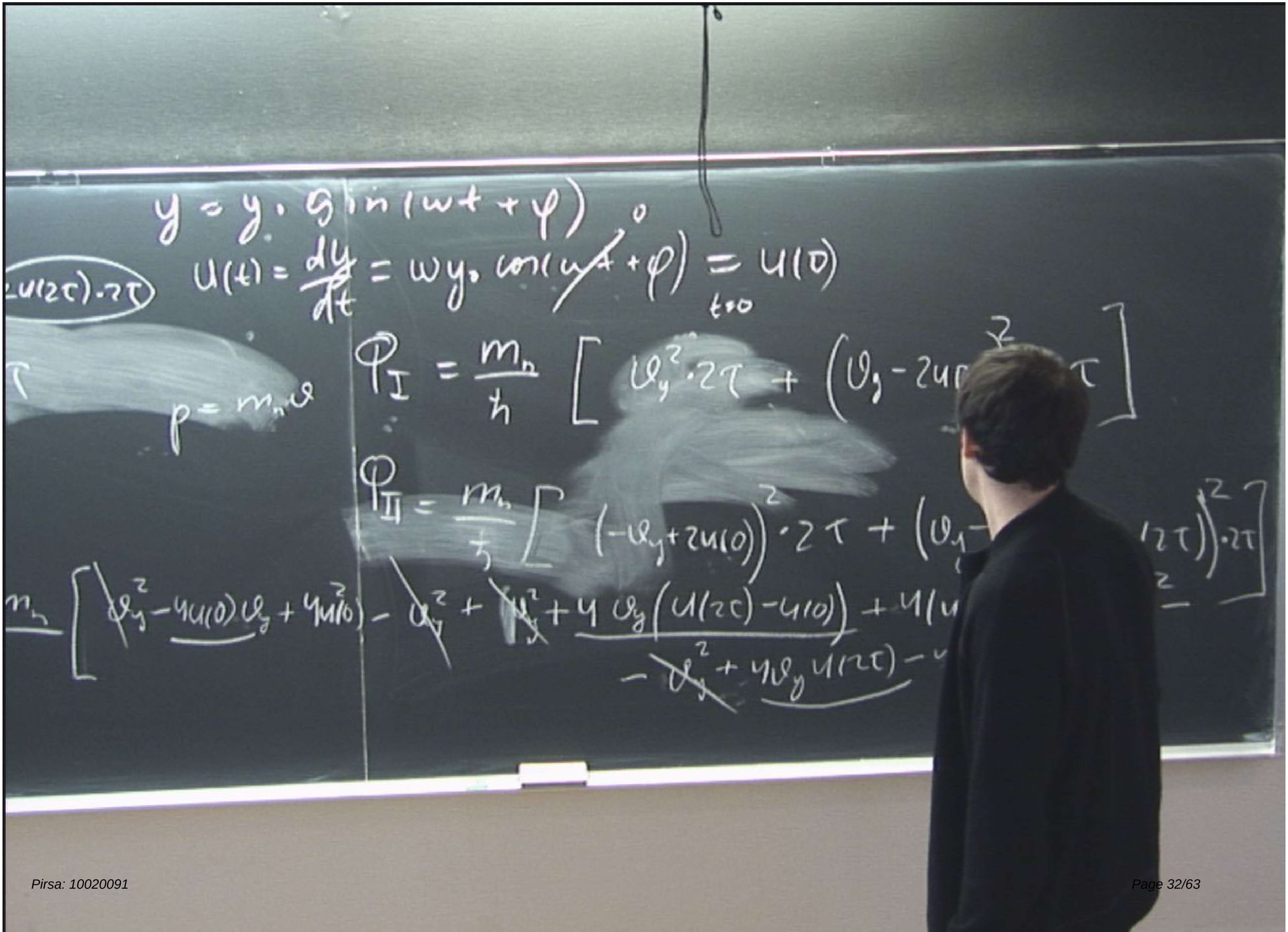
$$\Phi_I = \frac{m_n}{\hbar}\left[v_y^2 \cdot 2\tau + \left(v_y - 2u(0)\right)^2 \cdot 2\tau \right]$$

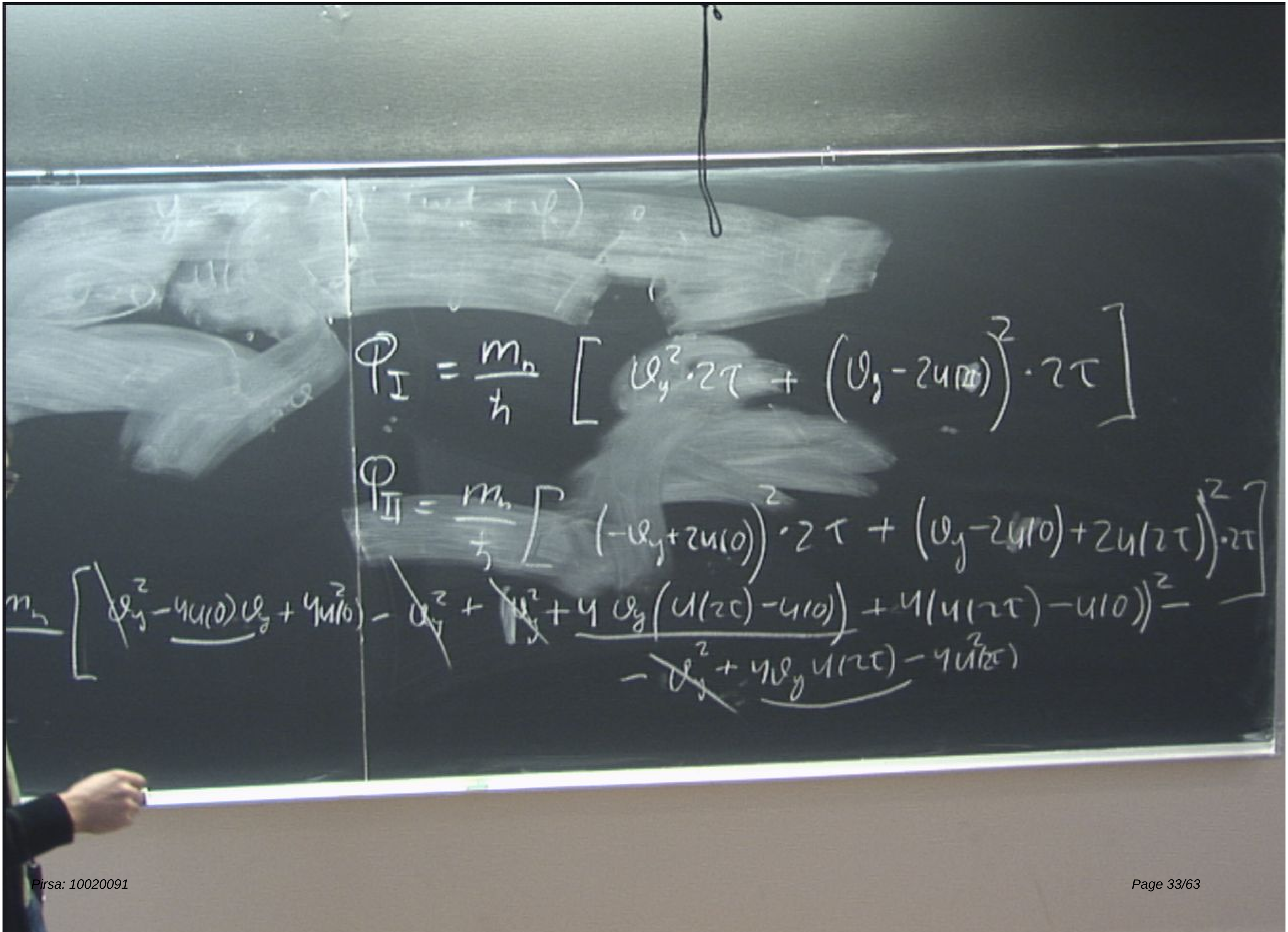
$$\Phi_{II} = \frac{m_n}{\hbar}\left[\left(-v_y + 2u(0)\right)^2 \cdot 2\tau + \left(v_y - 2u(0) + 2u(2\tau)\right)^2 \cdot 2\tau \right]$$

$$-4u(0) v_y + 4u^2(0)) - v_y^2 + (v_y^2 + 4 v_y\left(u(2\tau) - u(0)\right) + 4\left(u(2\tau) - u(0)\right)^2 -$$

$$- v_y^2 + 4 v_y u(2\tau) - 4u^2(2\tau))$$

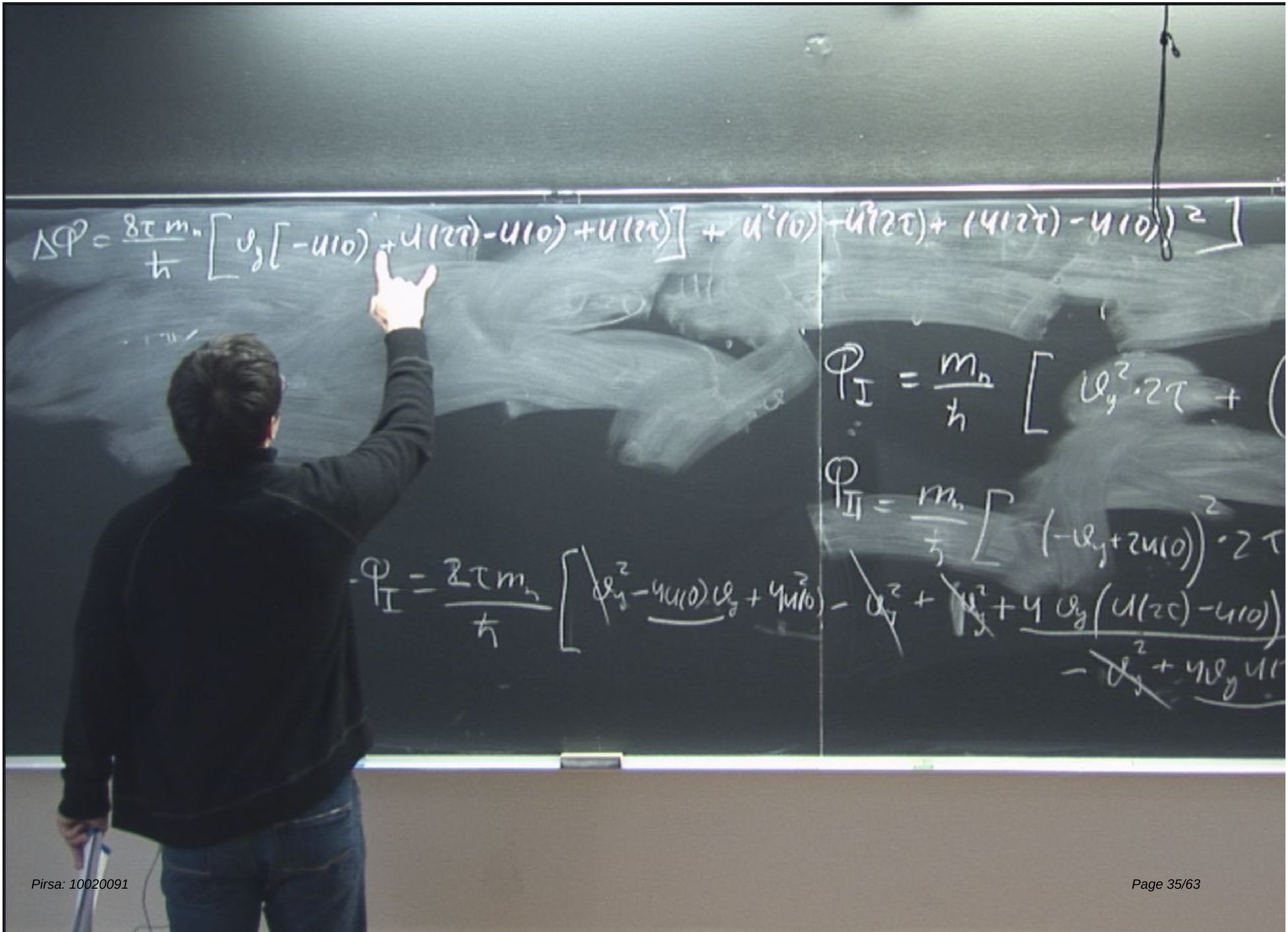

y = y₀ sin(ωt + φ)
u(t) = dy/dt = ωy₀ cos(ωt + φ) = u(0)
t=0
p = mₙv
φI = mₙ/ħ [vy² · 2τ + (vy − 2u(0))² · 2τ]
φII = mₙ/ħ [(−vy + 2u(0))² · 2τ + (vy − 2u(0) + 2u(2τ))²]
−4u(0) vy + 4u²(0) − vy² + vy² + 4 vy (u(2τ) − u(0)) + 4(u(2τ) − u(0))² −
− vy² + 4vy u(2τ) − 4u²(2τ)


y = y0 sin(ωt + φ)
u(t) = dy/dt = ωy0 cos(ωt + φ) = u(0)


φ_I = m_n/ħ [v_y^2 · 2τ + (v_y − 2u(0))^2 · 2τ]
φ_II = m_n/ħ [(−v_y + 2u(0))^2 · 2τ + (v_y − 2u(0) + 2u(2τ))^2 · 2τ]
m_n [v_y^2 − 4u(0)v_y + 4u^2(0) − v_y^2 + v_y^2 + 4 v_y (u(2τ) − u(0)) + 4(u(2τ) − u(0))^2 −
− v_y^2 + 4v_y u(2τ) − 4u^2(2τ)

$$\Delta\varphi = \frac{8\pi m_n}{\hbar}\left[\vartheta_y\left[-u(0)\right) + u(2\pi) - u(0)\right)$$

$$\Delta\varphi = \varphi_{II} - \varphi_{I} = \frac{8\pi m_n}{\hbar}\left[\vartheta_y^2 - 4u(0)\vartheta_y + 4u^2(0)\right) -$$


ΔΦ = 8τ m_n / ħ [ϑ_y [−u(0) + u(2τ) − u(0) + u(2τ)] + u²(0) − u²(2τ) + (u(2τ) − u(0))²]
Φ_I = m_n / ħ [ϑ_y² · 2τ +
Φ_II = m_n / ħ [(−ϑ_y + 2u(0))² · 2τ
−Φ_I = 8τ m_n / ħ [ϑ_y² − 4u(0) ϑ_y + 4u²(0) − ϑ_y² + ϑ_y² + 4 ϑ_y (u(2τ) − u(0))
− ϑ_y² + 4ϑ_y u

$$\Delta\varphi = \frac{8\tau m_n}{\hbar}\Big[\vartheta_y\big[-u(0) + u(2\tau) - u(0) + u(2\tau)\big] + u^2(0) - u^2(2\tau) + \big(u(2\tau) - u(0)\big)^2\Big]$$

$$-2\big(-u(0) + u(2\tau)\big)\Big) \qquad \big(u(0) - u(2\tau)\big)\big[u(0) + u(2\tau) + u(0) - \ldots$$

$$\varphi_I = \frac{m_n}{\hbar}\Big[\vartheta_y^2 \cdot 2\tau + (\ldots$$

$$\varphi_{II} = \frac{m_n}{\hbar}\Big[\big(-\vartheta_y + 2u(0)\big)^2 \cdot 2\tau \ldots$$

$$\Delta\varphi = \varphi_{II} - \varphi_I = \frac{8\tau m_n}{\hbar}\Big[\vartheta_y^2 - 4u(0)\vartheta_y + 4u^2(0) - \vartheta_y^2 + \vartheta_y^2 + 4\vartheta_y\big(u(2\tau) - u(0)\big) \ldots$$

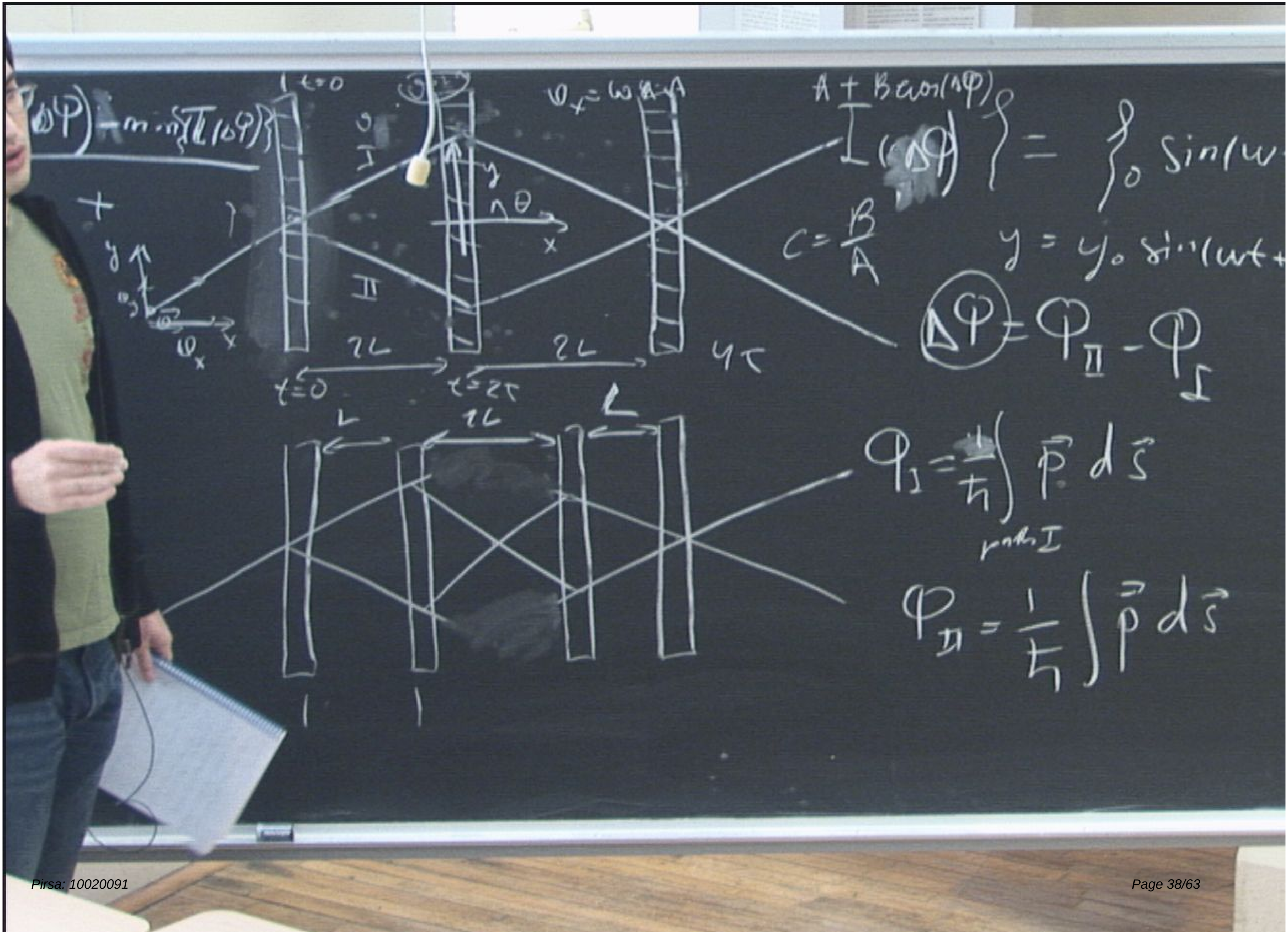
$$- \vartheta_y^2 + 4\vartheta_y u(\ldots$$

$$\Delta\varphi = \frac{8\tau m_n}{\hbar}\left[v_y\left[-u(0) + u(2\tau) - u(0) + u(2\tau)\right] + u^2(0) \right.$$

$$-2\,(-u(0) + u(2\tau))\big) \qquad (u(0)$$

$$\Delta\varphi_3 = \frac{16\tau m_n}{\hbar}\left(v_y - u(0)\right)\left(u(2\tau) - u(0)\right)$$

$$\Delta\varphi = \varphi_{II} - \varphi_I = \frac{8\tau m_n}{\hbar}\left[v_y^2 - 4u(0)v_y + 4u^2(0) \right)$$


t=0
2L
L
4τ
C = B/A
ΔΦ = Φ_II − Φ_I
Φ_I = 1/ħ ∫ p ds
path I
Φ_II = 1/ħ ∫ p ds

$$\Delta\varphi = \frac{8\tau m_n}{\hbar}\Big[v_y[-u(0) + u(2\tau) - u(0) + u(2\tau)] + u^2(0)$$

$$-2(-u(0) + u(2\tau))\Big) \qquad (u(0)$$

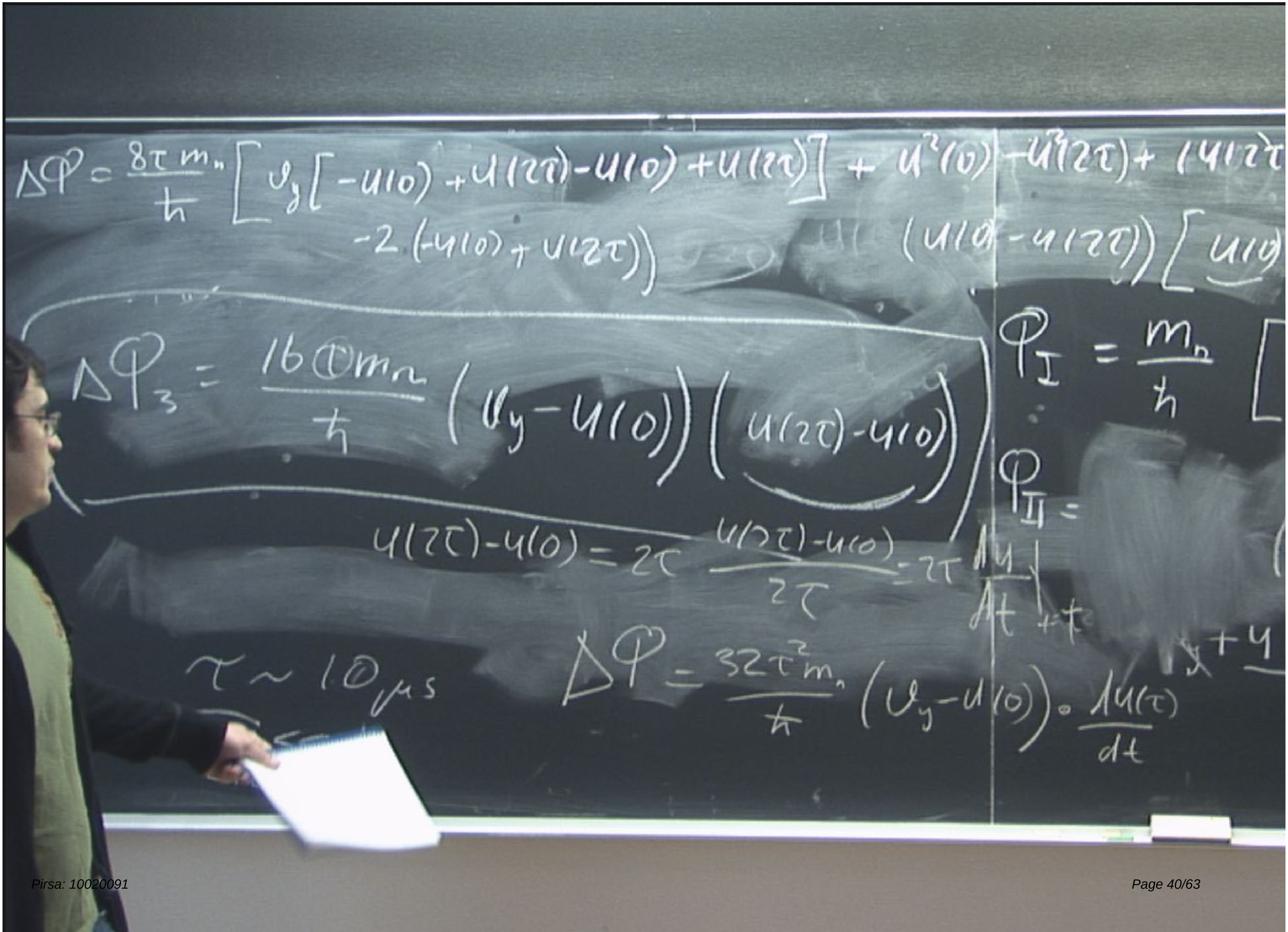
$$\Delta\varphi_3 = \frac{16\tau m_n}{\hbar}\left(v_y - u(0)\right)\left(u(2\tau) - u(0)\right)$$

$$u(2\tau) - u(0) = 2\tau \frac{u(2\tau) - u(0)}{2\tau} = 2\tau \frac{du}{dt}$$

$\tau \sim 10\,\mu s$

$\omega\tau \ll 1$

$< 1\,km$


ΔΦ = 8τ m_n / ħ [v_y [-u(0) + u(2τ) - u(0) + u(2τ)] + u²(0) - u²(2τ) +
-2 (-u(0) + u(2τ)))
(u(0) - u(2τ)) [u(0)
ΔΦ_3 = 16 τ m_n / ħ (v_y - u(0)) (u(2τ) - u(0))
Φ_I = m_n / ħ [
Φ_II =
u(2τ) - u(0) = 2τ (u(2τ) - u(0)) / 2τ = 2τ du/dt |_{t=τ}
τ ~ 10 μs
ΔΦ = 32τ² m_n / ħ (v_y - u(0)) · du(τ)/dt

$$\Delta\varphi = \frac{8\tau m_n}{\hbar}\Big[v_y\big[-u(0) + u(2\tau) - u(0) + u(2\tau)\big] + u^2(0) - u^2(2\tau) + (u(2\tau$$

$$-2\,(-u(0) + u(2\tau))\qquad (u(0) - u(2\tau))\big[\,u(0)$$

$$\boxed{\Delta\varphi_3 = \frac{16\,\tau\, m_n}{\hbar}\big(v_y - u(0)\big)\big(u(2\tau) - u(0)\big)}$$

$$\varphi_I = \frac{m_n}{\hbar}\Big[$$

$$\varphi_{II} =$$

$$u(2\tau) - u(0) = 2\tau\,\frac{u(2\tau) - u(0)}{2\tau} = 2\tau\,\frac{du}{dt}\Big|_{t=\tau}$$

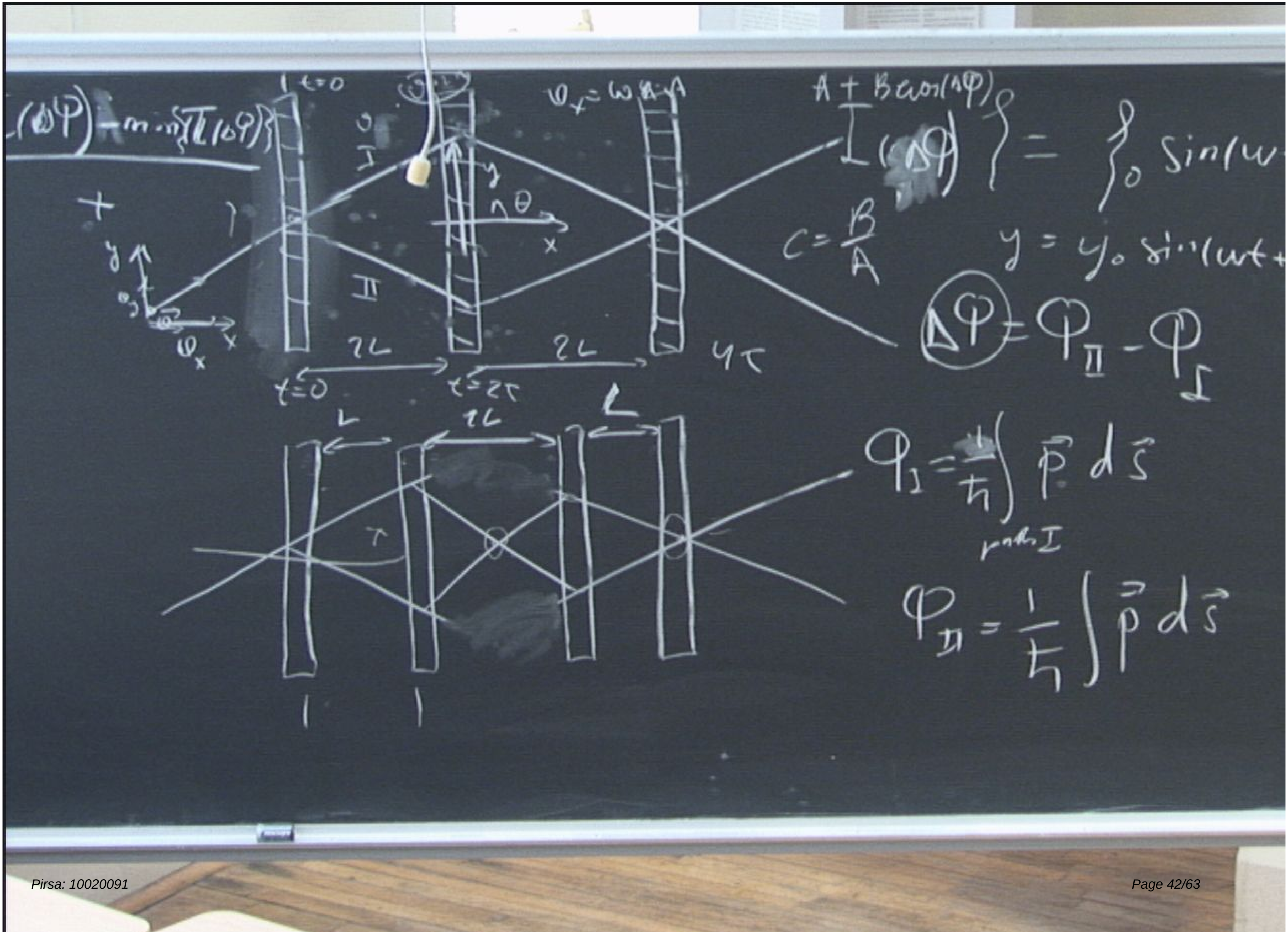
$$\tau \sim 10\,\mu s$$

$$\omega\tau \ll 1$$

$< 1\,km$

$$\Delta\varphi = \frac{32\tau^2 m_n}{\hbar}\big(v_y - u(0)\big)\cdot\frac{du(\tau)}{dt}$$

$$x + y$$


t=0
2L
t=2τ
4τ
L
A ± B cos(ΔΦ)
C = B/A
y = y₀ sin(ωt+
ΔΦ = Φ_II − Φ_I
Φ_I = 1/ħ ∫ p ds
path I
Φ_II = 1/ħ ∫ p ds

IV

$$\Phi_I = \frac{m_4}{\hbar} \Big[$$

IV

$$\Phi_I = -\frac{m}{\hbar}\tau\left[\theta_y^2 + \left(\vartheta - 2U(\tau)\right)^2\right]$$

IV

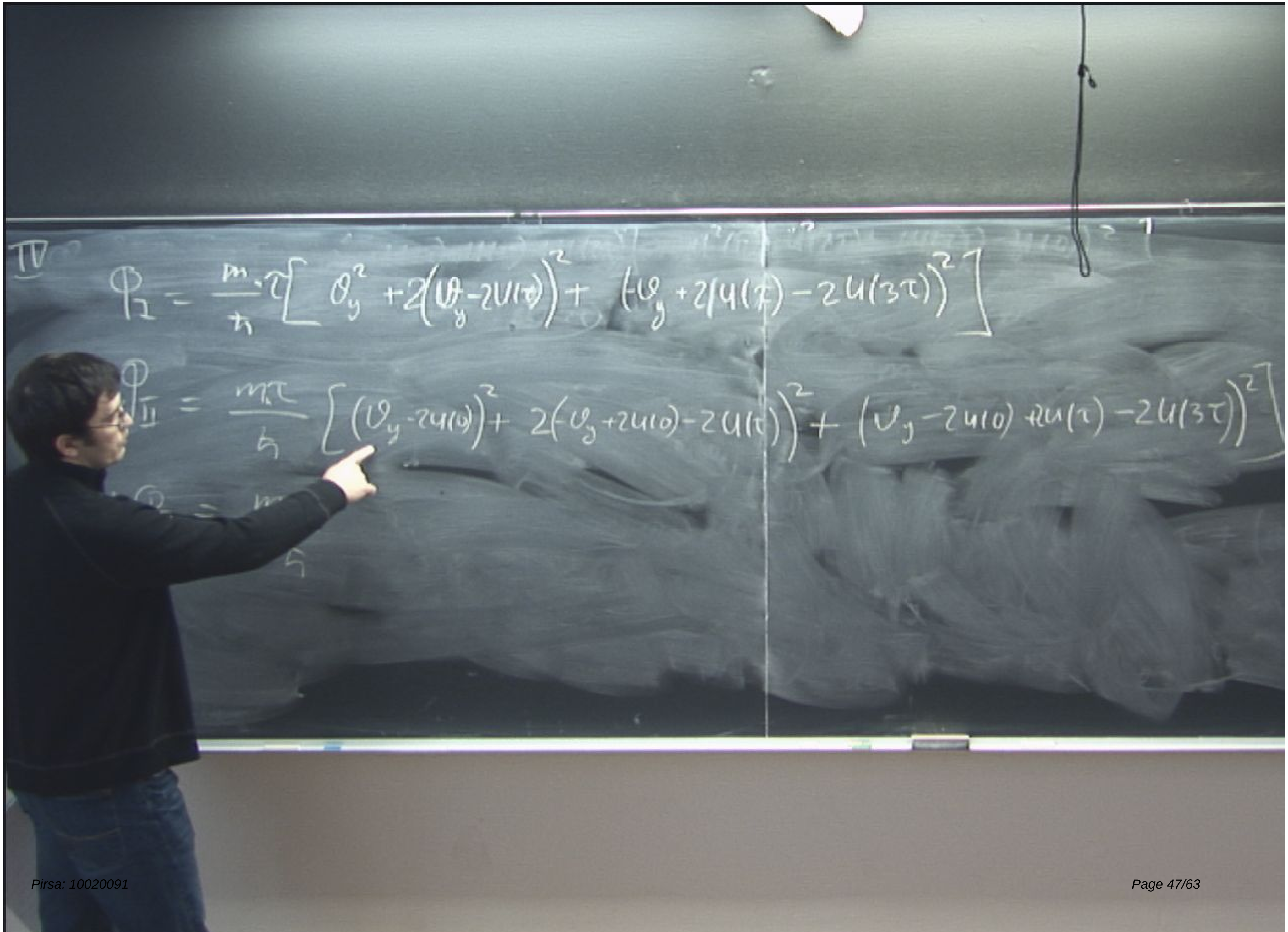
$$\Phi_I = \frac{m}{\hbar}\tau\left[\theta_y^2 + 2\left(\theta_y - 2U(\tau)\right)^2 + \left(-\theta_y + 2(U(\tau) - 2U(3\tau)\right)^2\right]$$

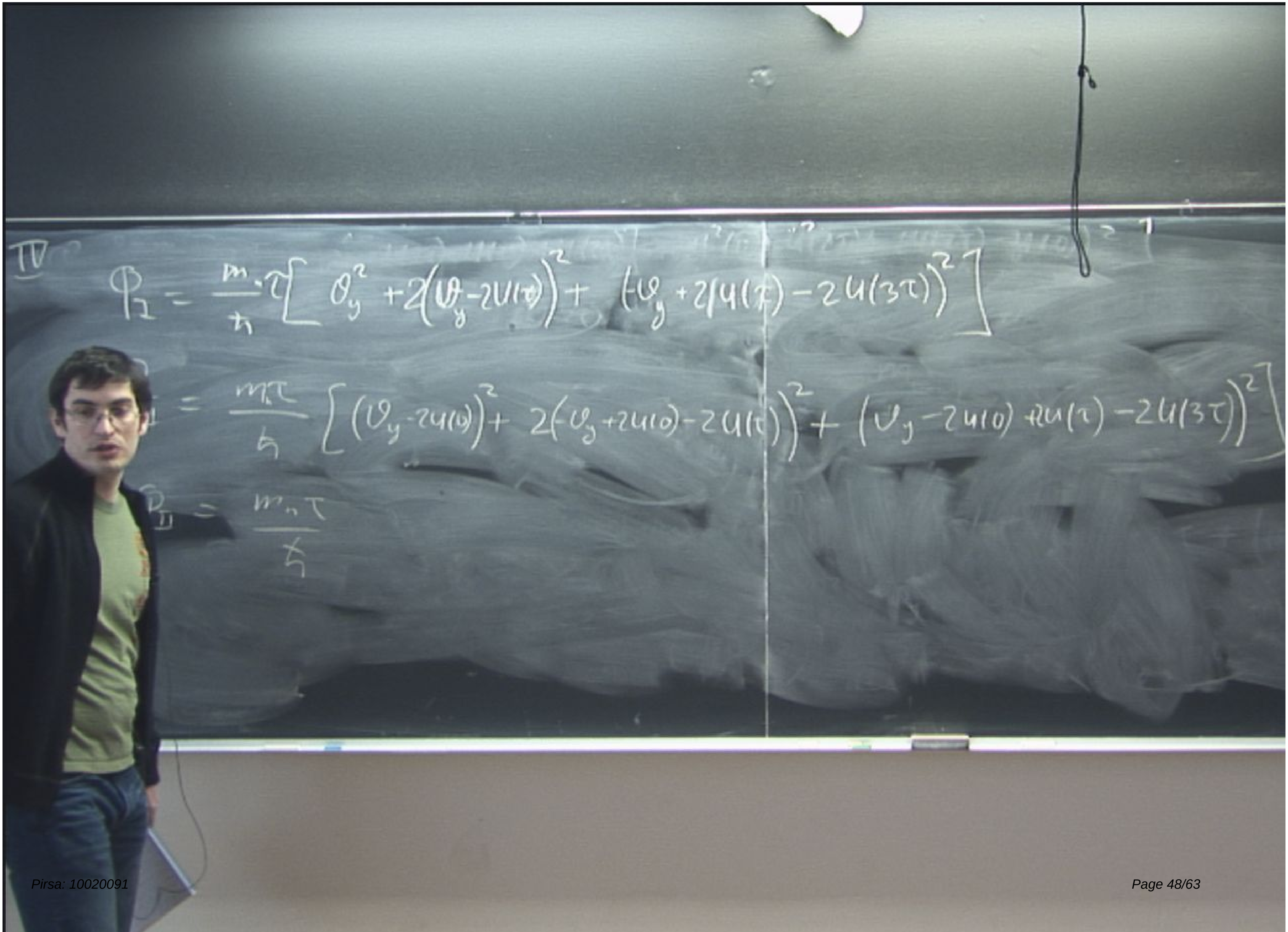
$$\Phi_{II} = \frac{m\tau}{\hbar}$$

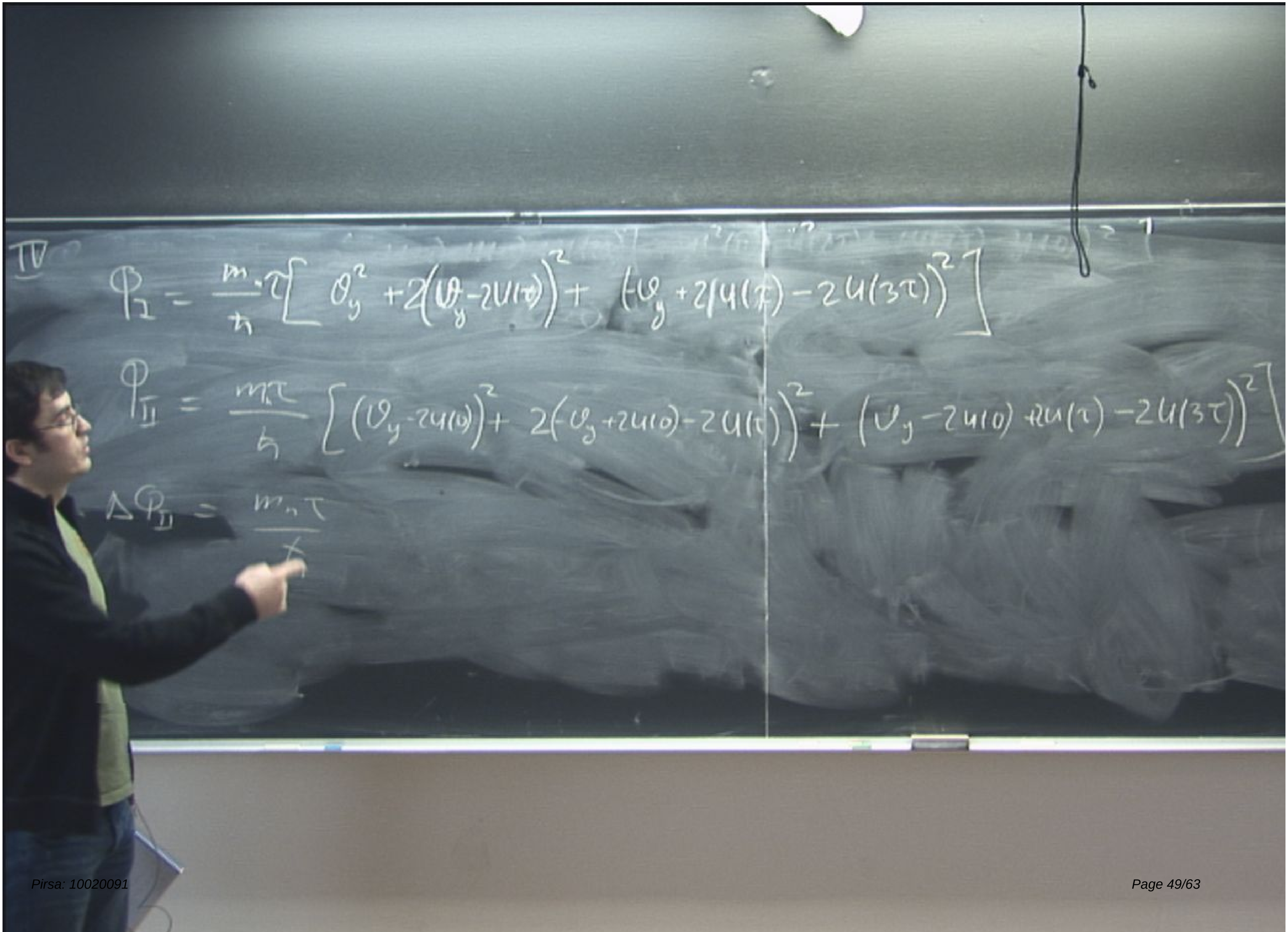
IV

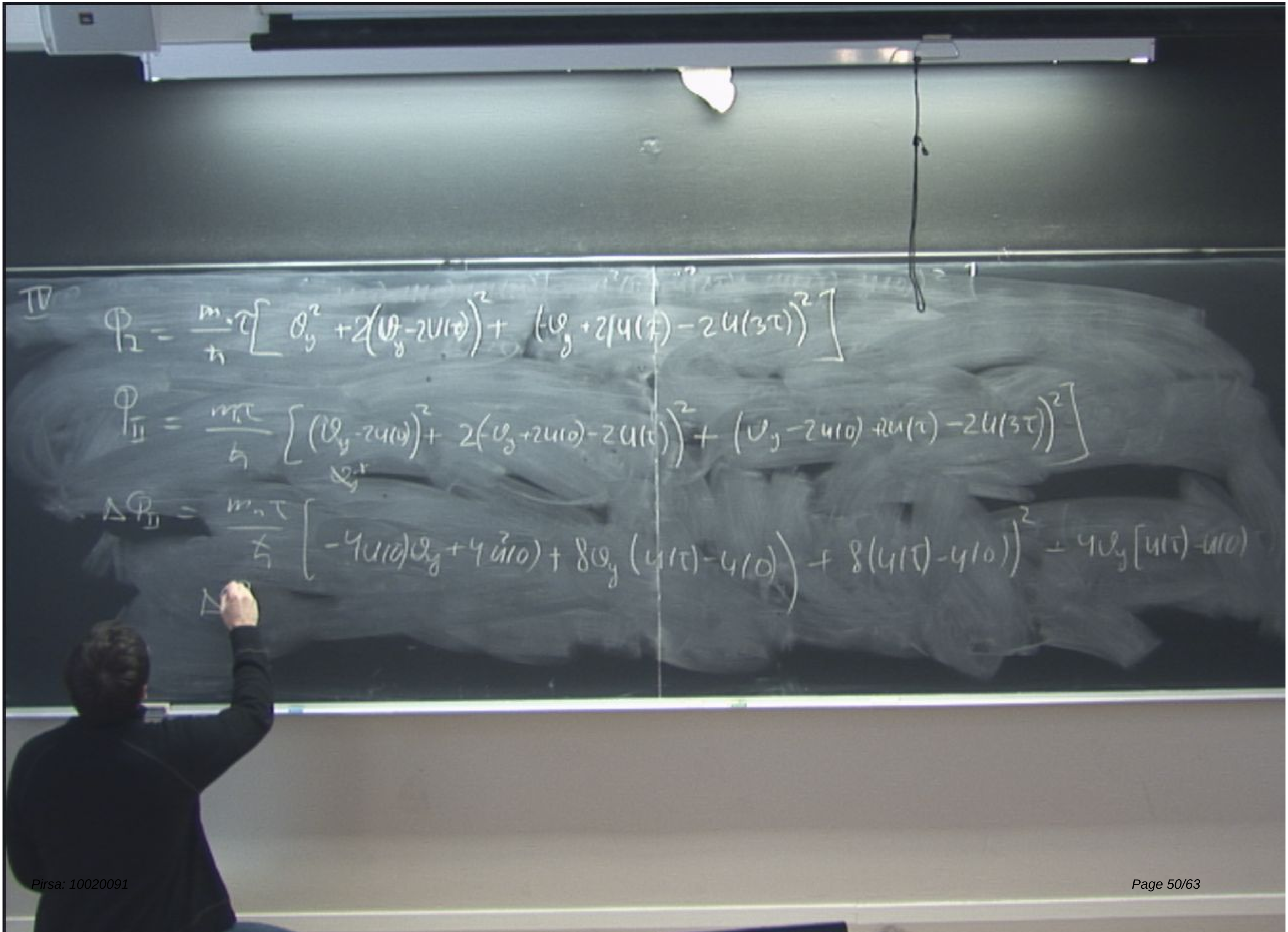
$$\Phi_{I} = \frac{m_1 \tau}{\hbar}\left[\, \theta_y^2 + 2\left(\theta_y - 2u(\tau)\right)^2 + \left(-\theta_y + 2\left(u(\tau) - 2u(3\tau)\right)\right)^2 \right]$$

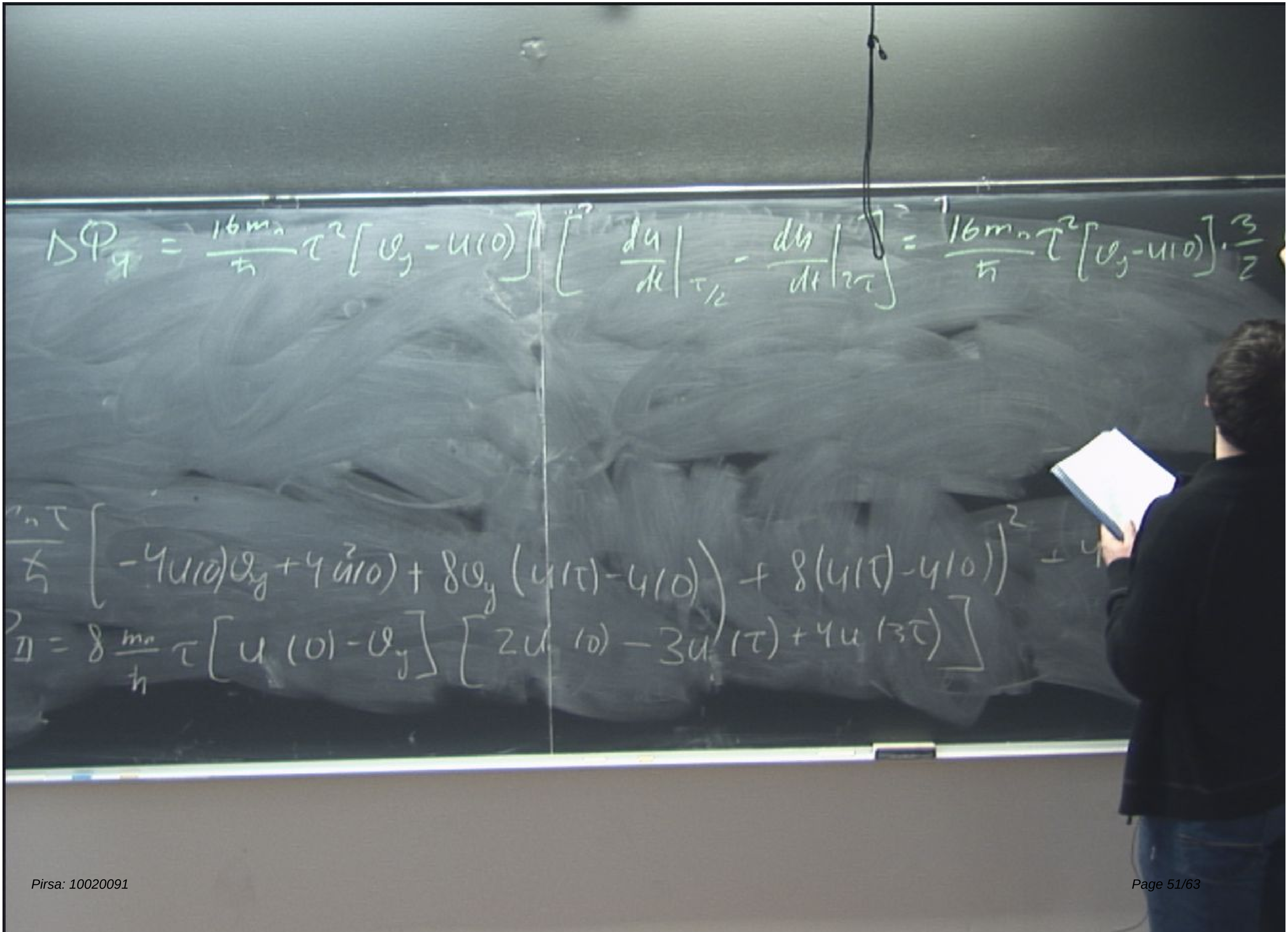
$$\Phi_{II} = \frac{m_1 \tau}{\hbar}\left[\left(\theta_y - 2u(0)\right)^2 + \left(-\theta_y + 2u(0) - 2u(\tau)\right)^2\right.$$

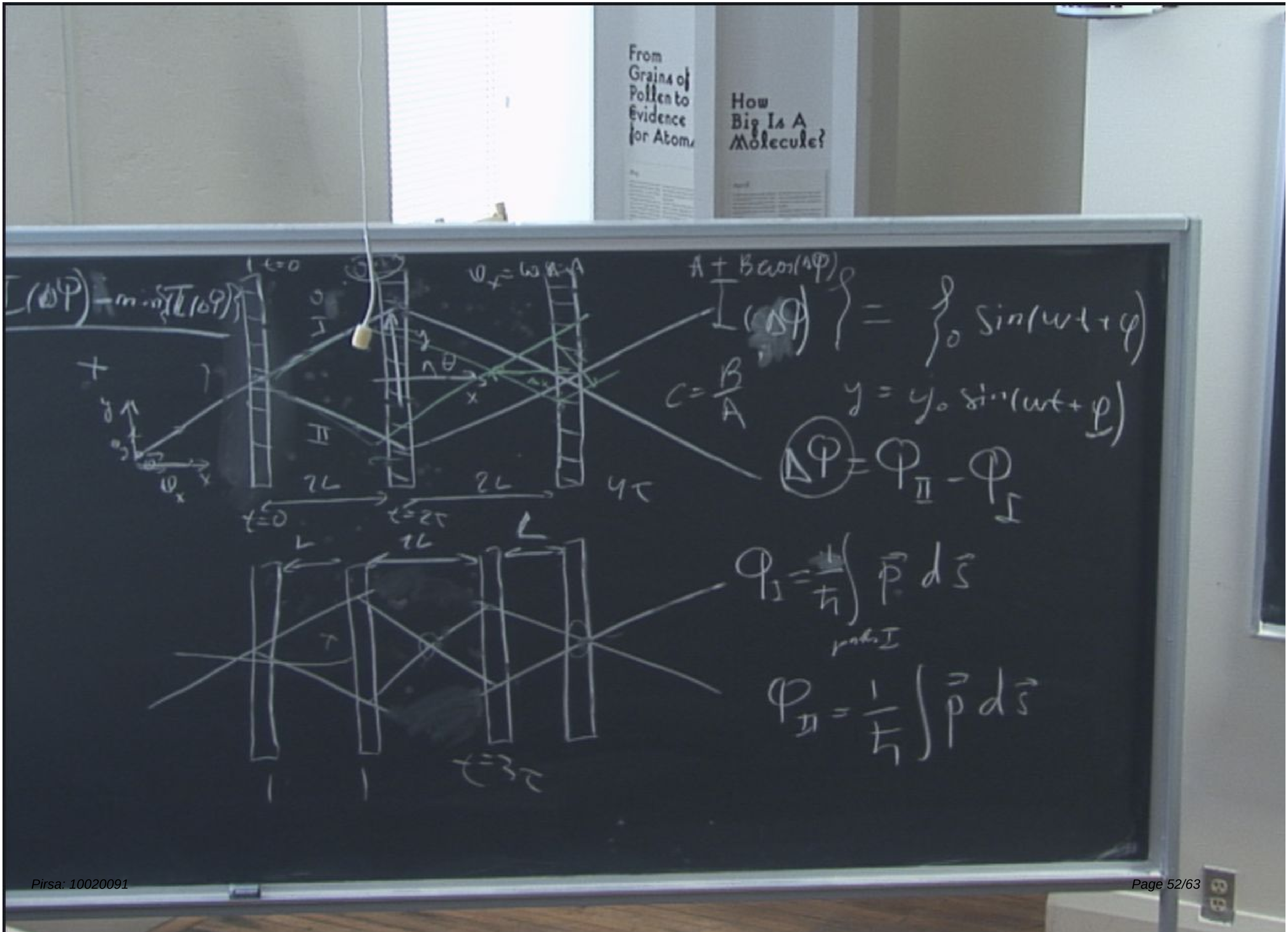

IV
$\Phi_I = \frac{m}{\hbar}\tau\left[\vartheta_y^2 + 2(\vartheta_y - 2u(\tau))^2 + (-\vartheta_y + 2(u(\tau) - 2u(3\tau))^2\right]$
$\Phi_{II} = \frac{m\tau}{\hbar}\left[(\vartheta_y - 2u(0))^2 + 2(-\vartheta_y + 2u(0) - 2u(\tau))^2 + (\vartheta_y - 2u(0) + 2u(\tau) - 2u(3\tau))^2\right]$

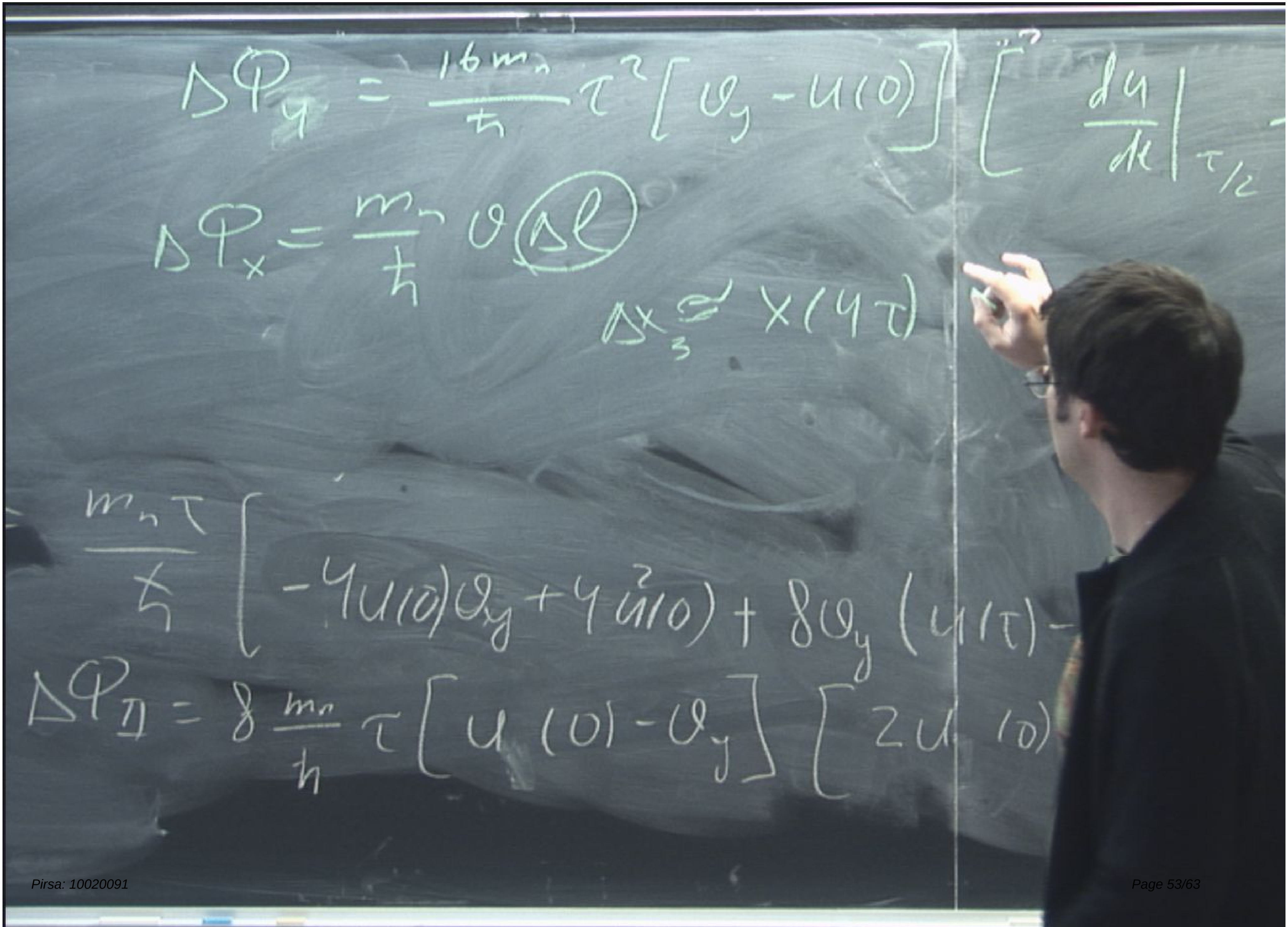

IV
Φ_I = m_n τ / ħ [ϑ_y^2 + 2(ϑ_y − 2u(τ))^2 + (−ϑ_y + 2(u(τ) − 2u(3τ))^2]
= m_n τ / ħ [(ϑ_y − 2u(0))^2 + 2(−ϑ_y + 2u(0) − 2u(τ))^2 + (ϑ_y − 2u(0) + 2u(τ) − 2u(3τ))^2]
Φ_II = m_n τ / ħ

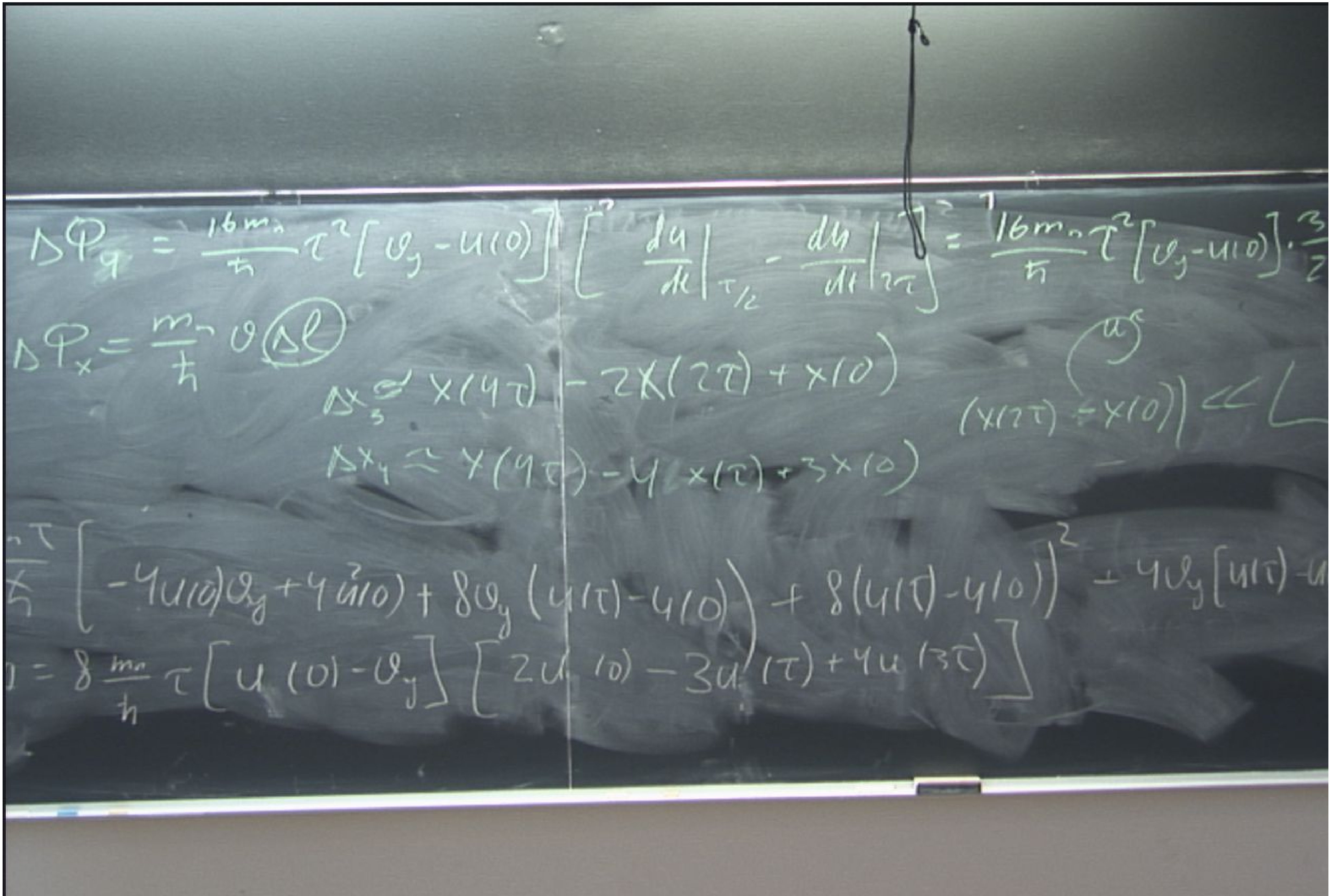

IV
φ_I = m_n τ/ħ [θ_y² + 2(θ_y − 2u(τ))² + (−θ_y + 2(u(τ) − 2u(3τ))²]
φ_II = m_n τ/ħ [(θ_y − 2u(0))² + 2(−θ_y + 2u(0) − 2u(τ))² + (θ_y − 2u(0) + 2u(τ) − 2u(3τ))²]
Δφ_II = m_n τ/ħ

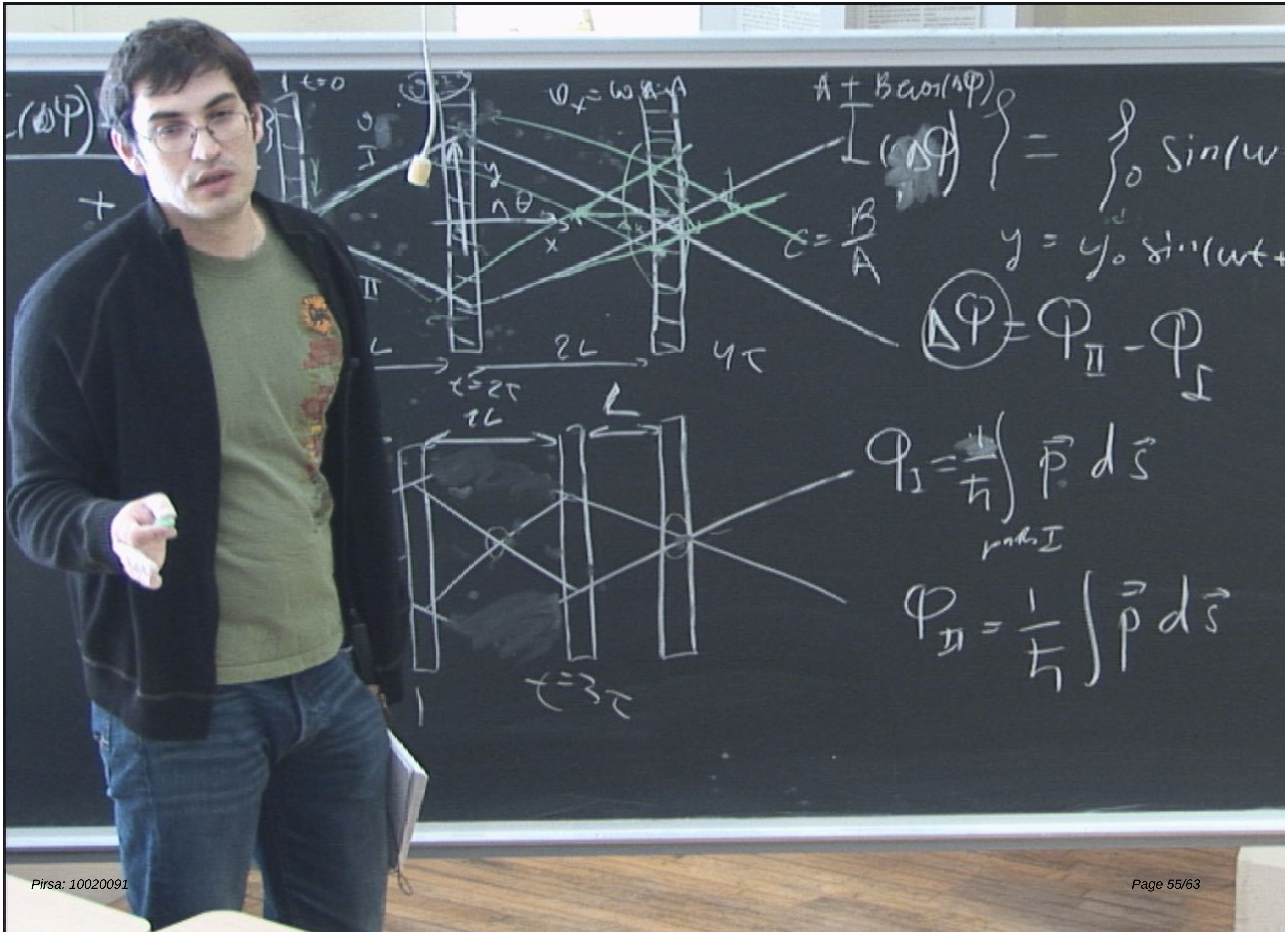

IV
Φ_I = m_n τ / ħ [θ_g² + 2(θ_g − 2u(τ))² + (−θ_g + 2(u(τ) − 2u(3τ))²]
Φ_II = m_n τ / ħ [(θ_g − 2u(0))² + 2(−θ_g + 2u(0) − 2u(τ))² + (θ_g − 2u(0) + 2u(τ) − 2u(3τ))²]
ΔΦ_II = m_n τ / ħ [−4u(0)θ_g + 4u²(0) + 8θ_g (u(τ) − u(0)) + 8(u(τ) − u(0))² − 4θ_g [u(τ) − u(0)]


ΔΦ = 16m τ²/ħ [υ_y − u(0)] [du/dt|_{τ/2} − du/dt|_{2τ}] = 16m τ²/ħ [υ_y − u(0)] · 3/2
ħ [−4u(0)υ_y + 4u²(0) + 8υ_y (u(τ) − u(0)) + 8(u(τ) − u(0))²
= 8 m/ħ τ [u(0) − υ_y] [2u(0) − 3u(τ) + 4u(3τ)]

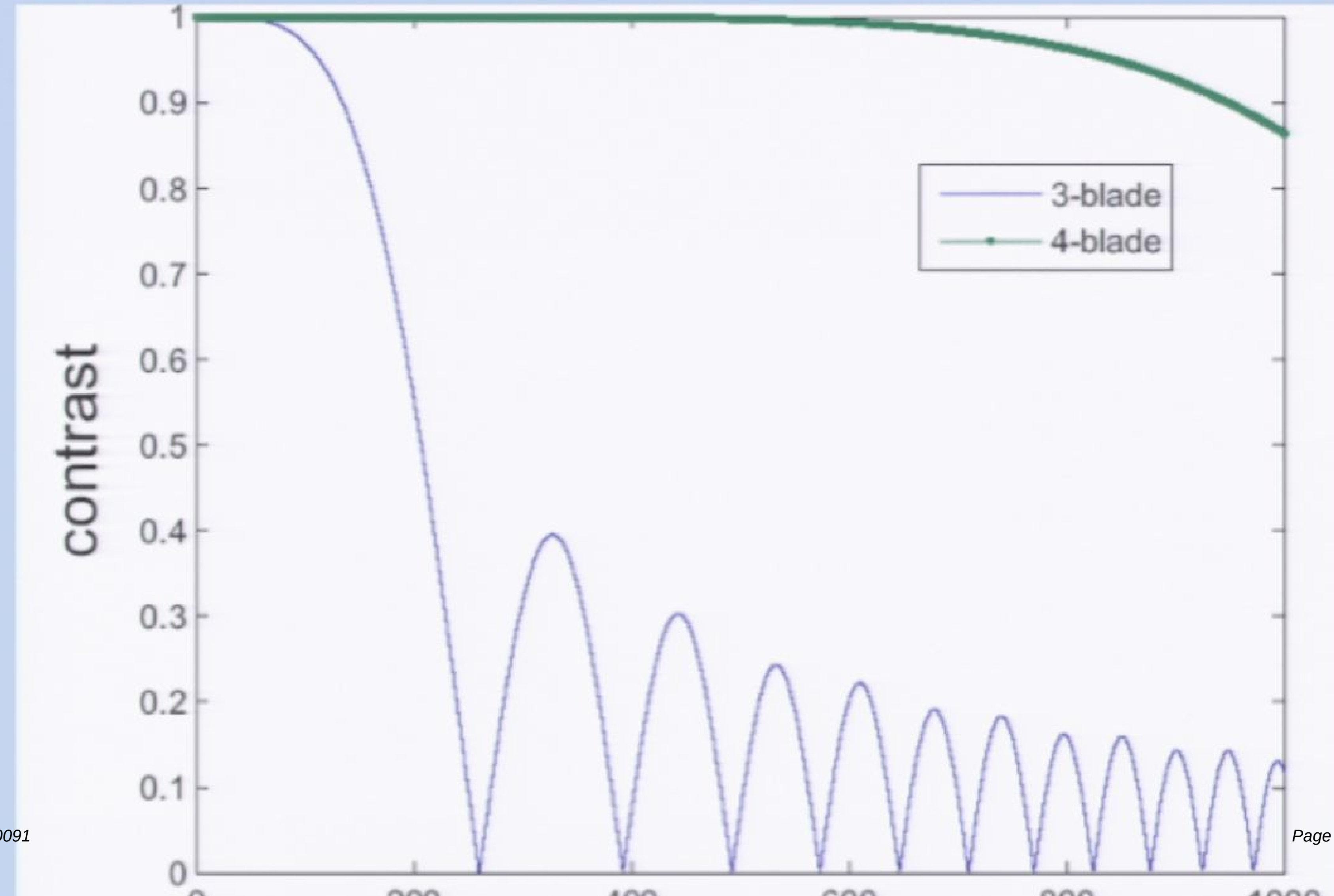

From Grains of Pollen to Evidence for Atoms
How Big Is A Molecule?
A ± B cos(Δφ)
C = B/A
y = y0 sin(wt + φ)
Δφ = φII − φI
t=0
t=2τ
t=3τ


ΔΦ_y = (16 m_n / ħ) τ² [ϑ_y − u(0)] [du/dt |_{τ/2}
ΔΦ_x = (m_n / ħ) ϑ Δl
Δx ≅ x(4τ)
(m_n τ / ħ) [−4u(0)ϑ_y + 4u²(0) + 8ϑ_y (u(τ) −
ΔΦ_II = 8 (m_n / ħ) τ [u(0) − ϑ_y] [2u(0)

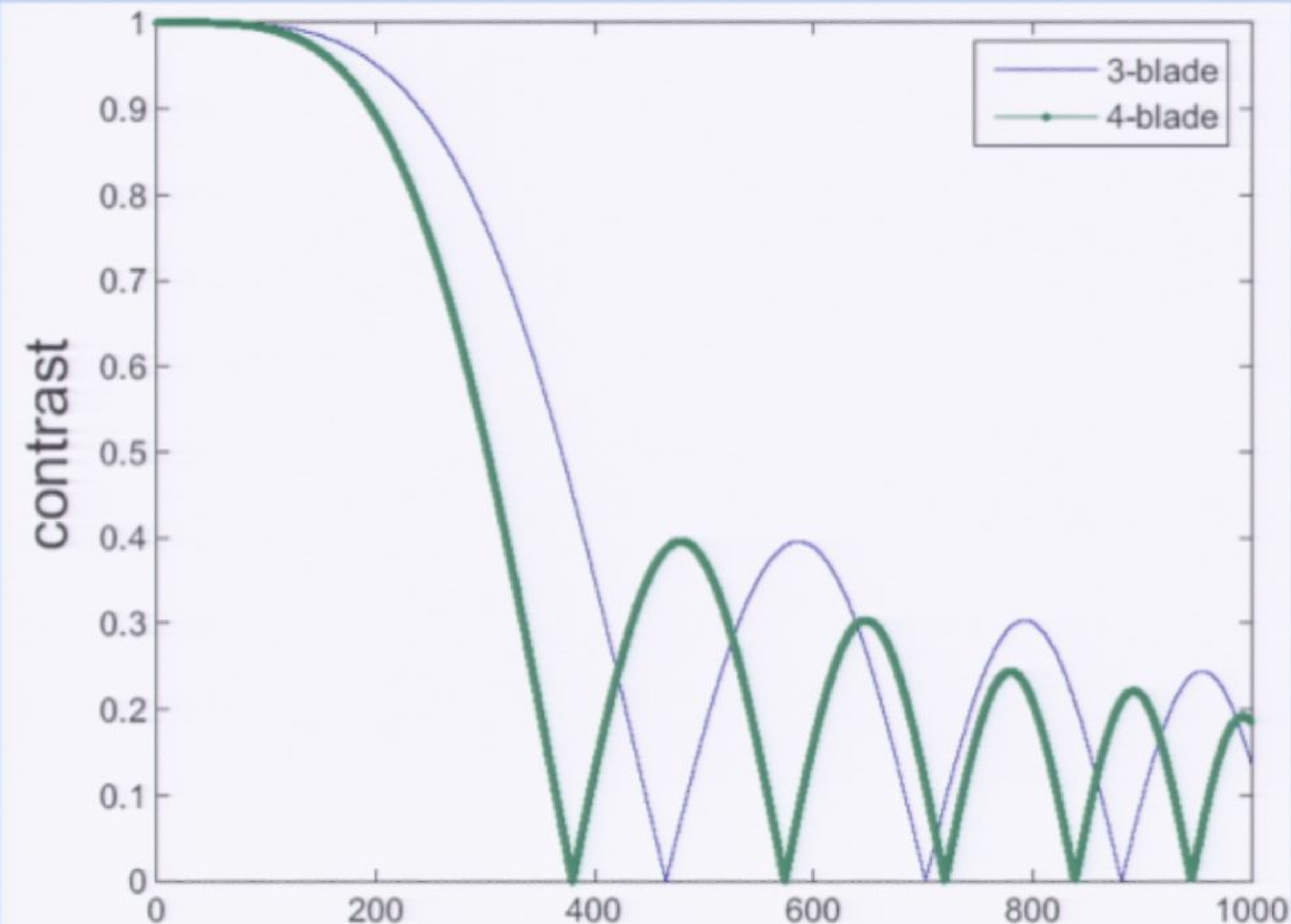

ΔΦy = 16m/ħ τ² [υy − u(0)] [du/dt|τ/2 − du/dt|2τ] = 16m/ħ τ² [υy − u(0)] · 3/2
ΔΦx = m/ħ υ Δl
Δx3 ≃ x(4τ) − 2x(2τ) + x(0)
(x(2τ) − x(0)) ≪ L
Δx4 ≃ x(4τ) − 4x(τ) + 3x(0)
[−4u(0)υy + 4u²(0) + 8υy (u(τ) − u(0)) + 8(u(τ) − u(0))² + 4υy [u(τ) −
= 8 m/ħ τ [u(0) − υy] [2u(0) − 3u(τ) + 4u(3τ)]


t=0
A ± B cos(ΔΦ)
I(ΔΦ)
C = B/A
ΔΦ = Φ_II − Φ_I
4τ
2L
L
t=2τ
2L
Φ_I = 1/ħ ∫ p ds
path I
Φ_II = 1/ħ ∫ p ds
t=3τ

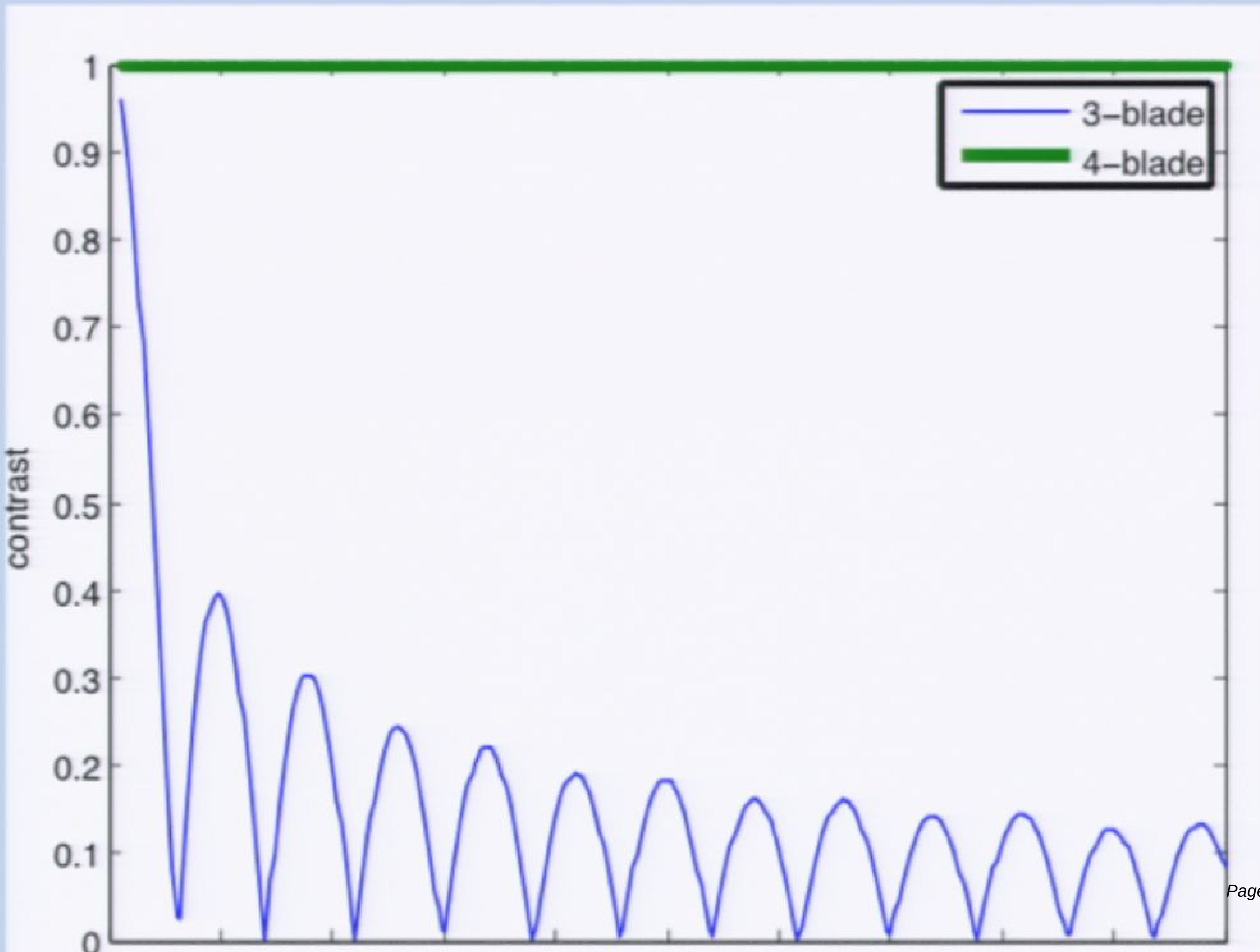
Numerical Simulations
Contrast due to vibration along y-axis



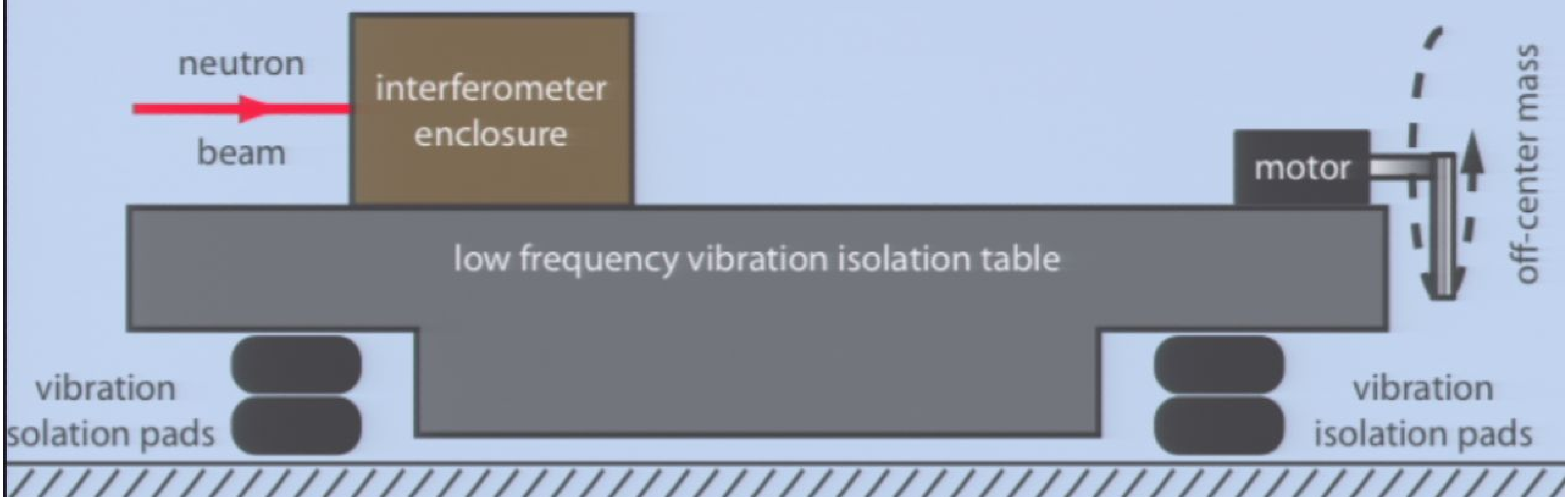
Numerical Simulations
Contrast due to vibration along x-axis



Numerical Simulations
Contrast due to rotational vibrations

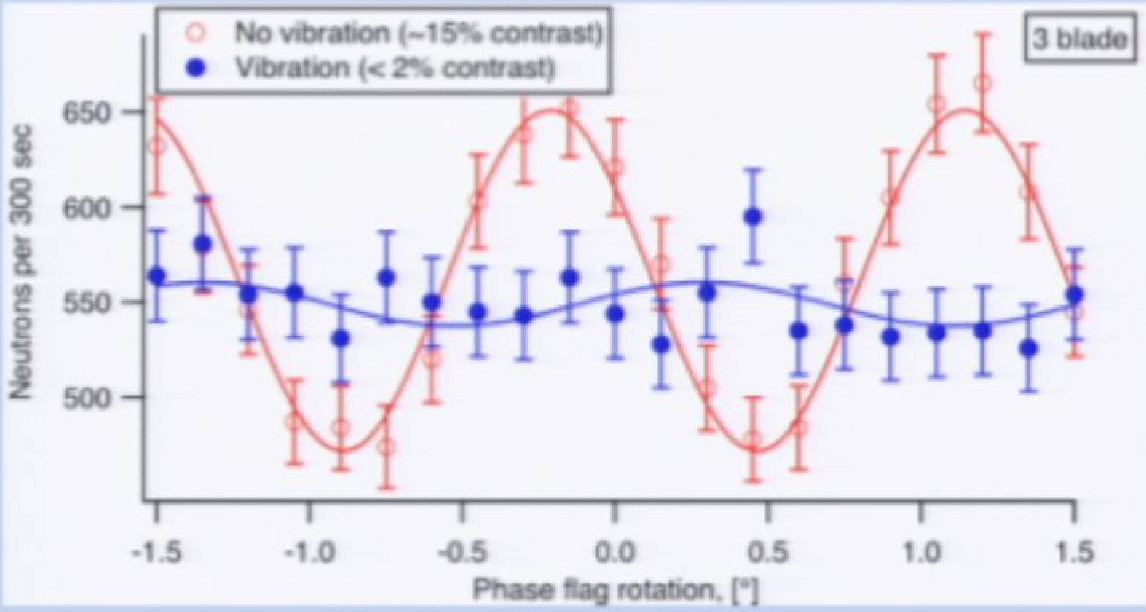


Experimental Setup



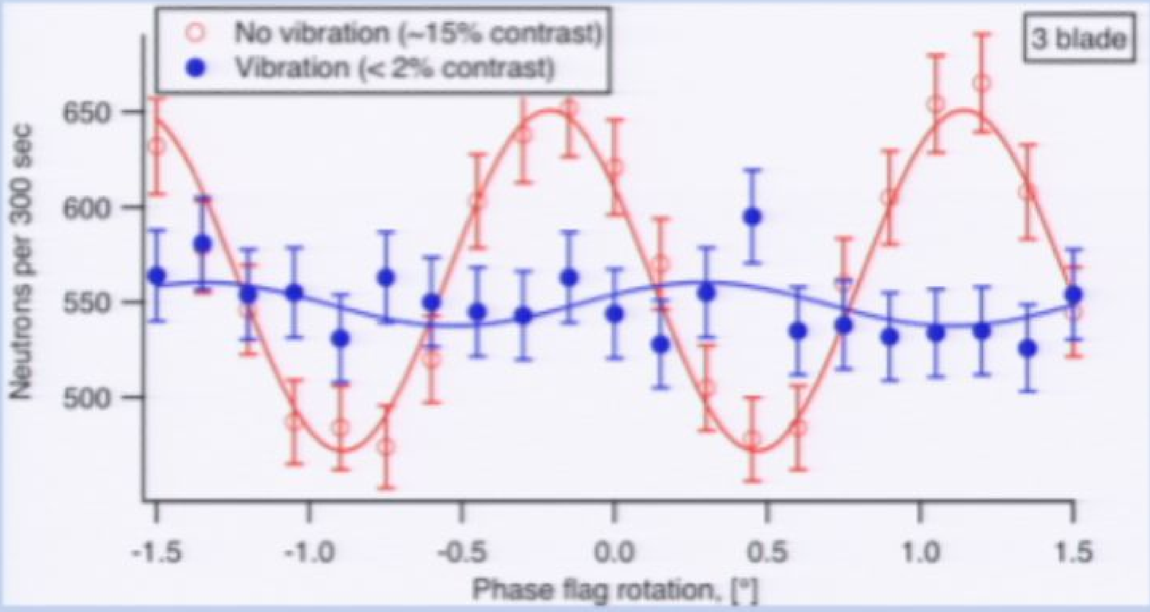
Experimental results
Application of 8 Hz vibrations

3 blade

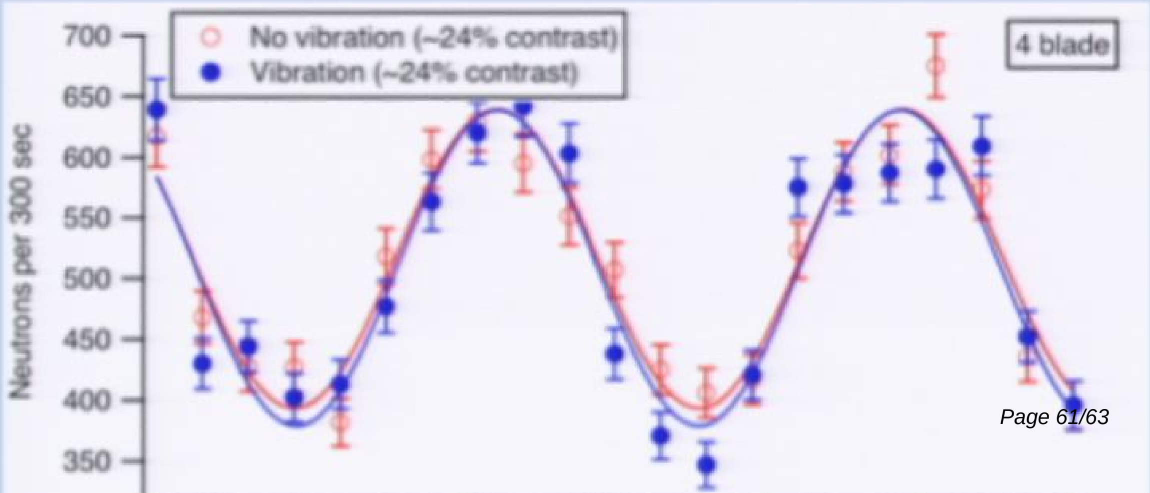


Experimental results
Application of 8 Hz vibrations

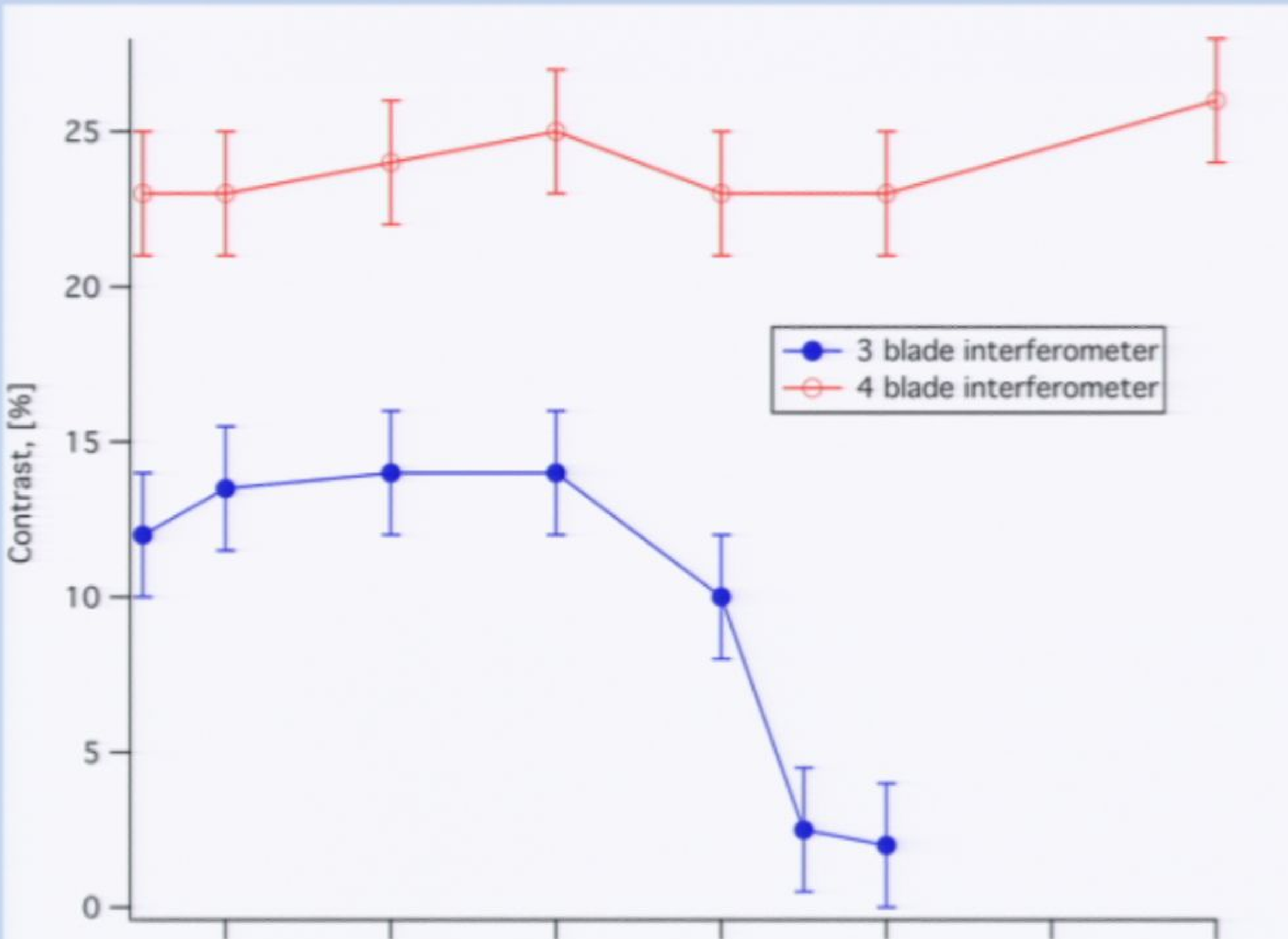
3 blade



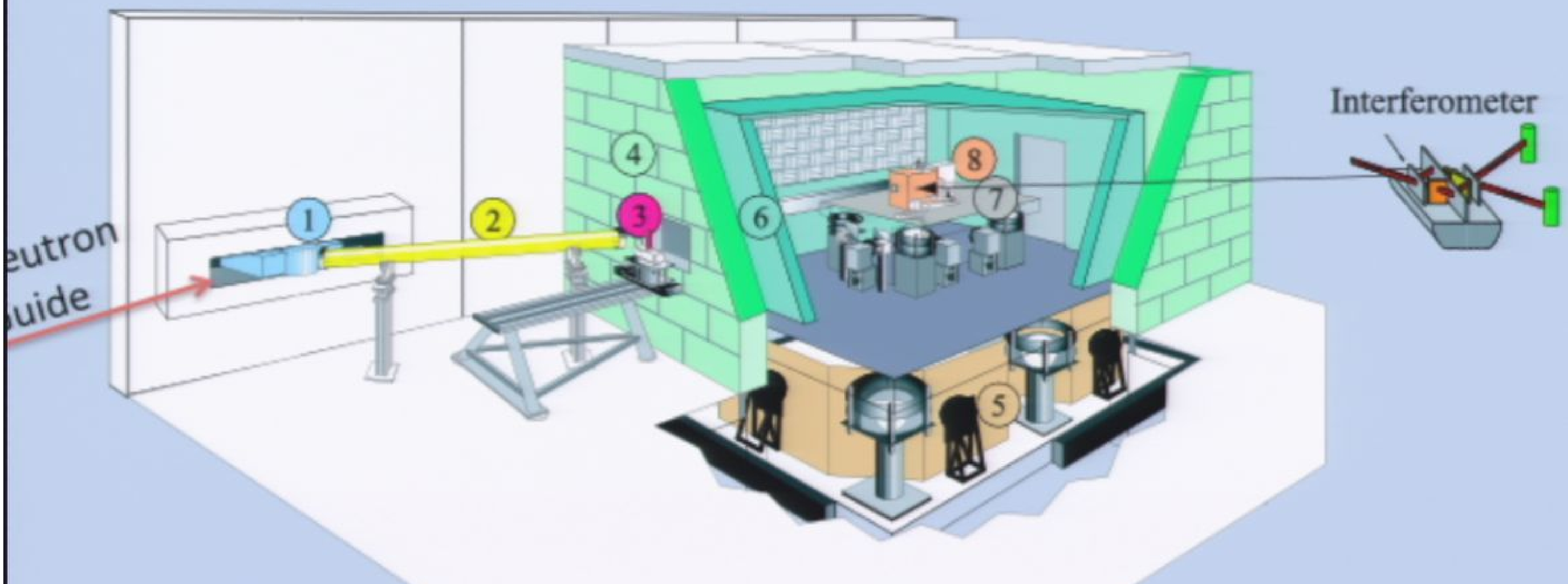
4 blade



Experimental results
Effect of vibrations on the contrast



he Neutron Interferometer and Optics Facility



Components:

- (1) Collimator/shutter
- (2) Helium filled beam transport tube
- (3) Focusing pyrolytic graphite monochromator
- (4) Outer environmental enclosure
- (5) Primary vibration isolation stage
- (6) Acoustic and thermal isolation enclosure
- (7) Secondary vibration isolation stage
- (8) Enclosure for interferometer and detectors

solated 40,000 Kg room is supported by six airsprings

Active Vibration Control eliminates vibrations less than 10hz