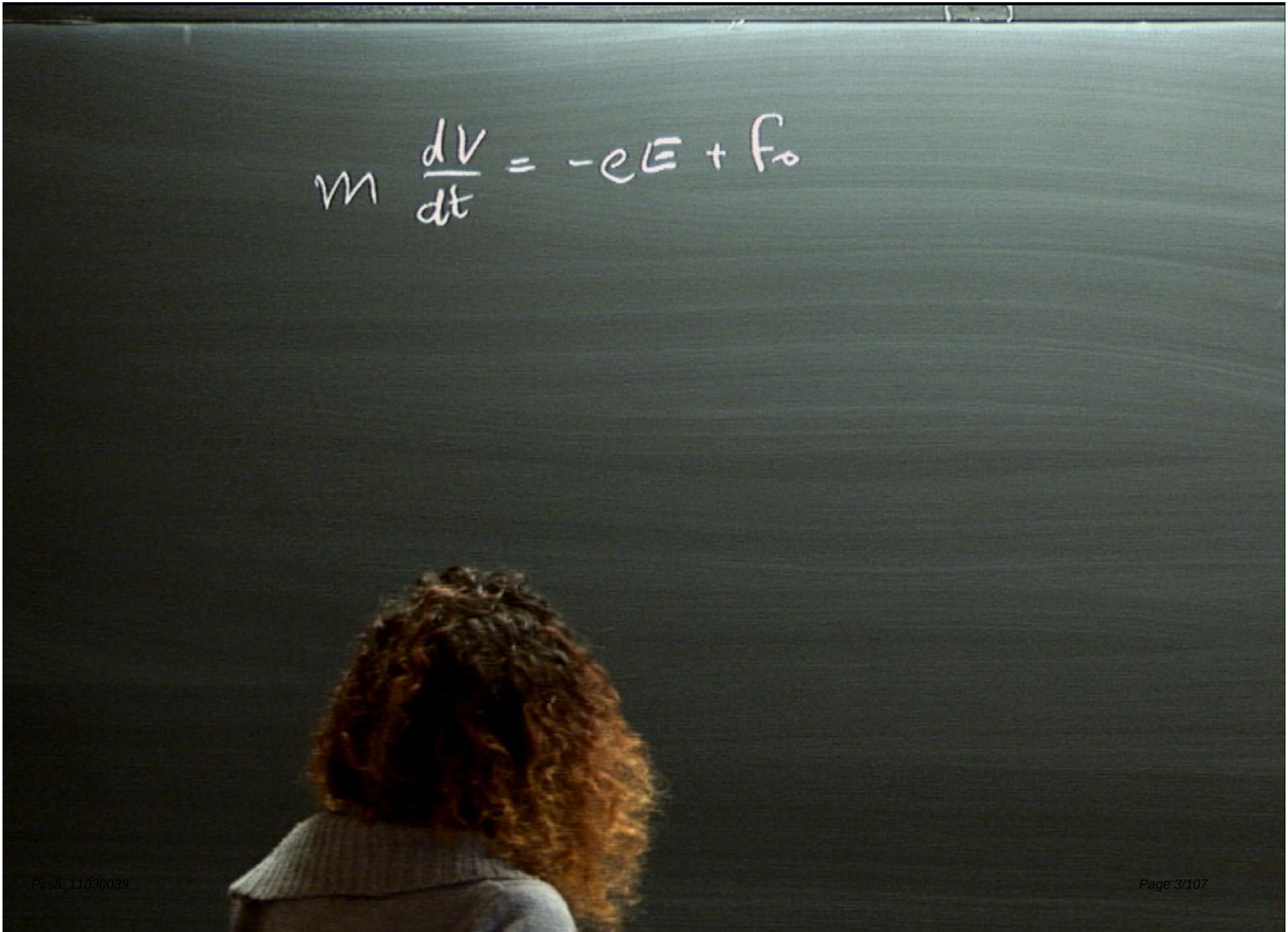
Title: Explorations in Condensed Matter - Lecture 6

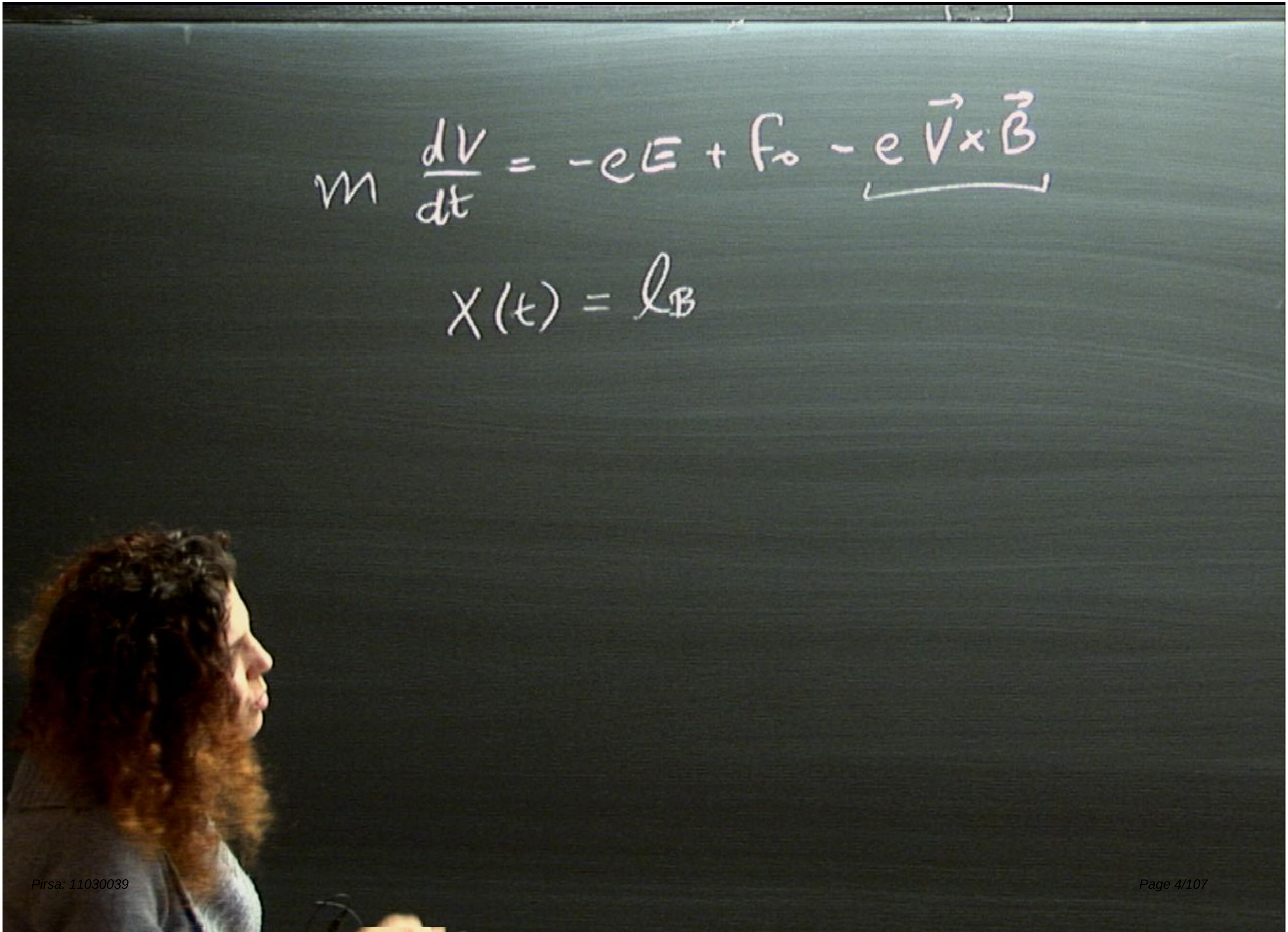
Date: Mar 21, 2011 10:15 AM

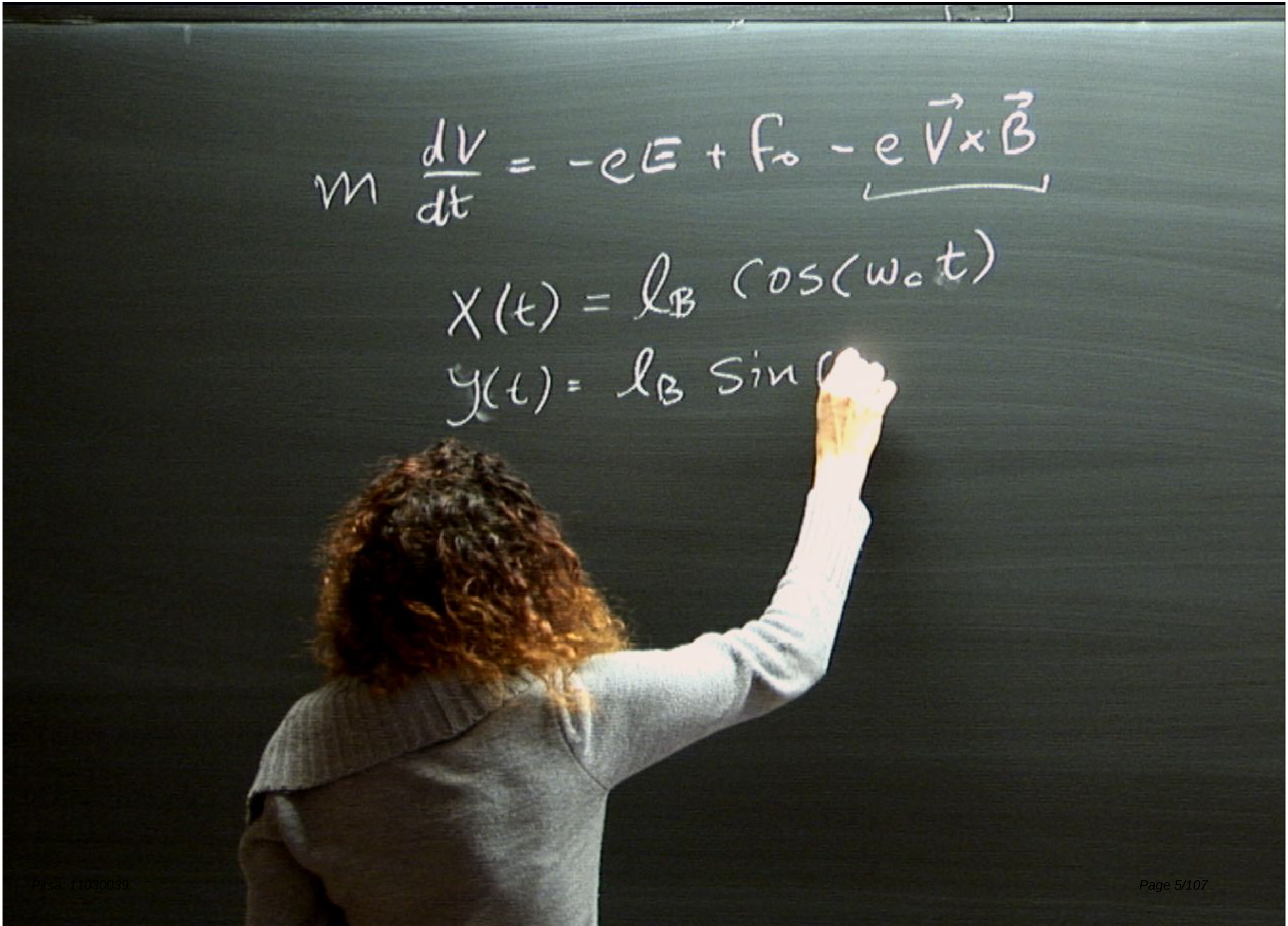
URL: http://pirsa.org/11030039

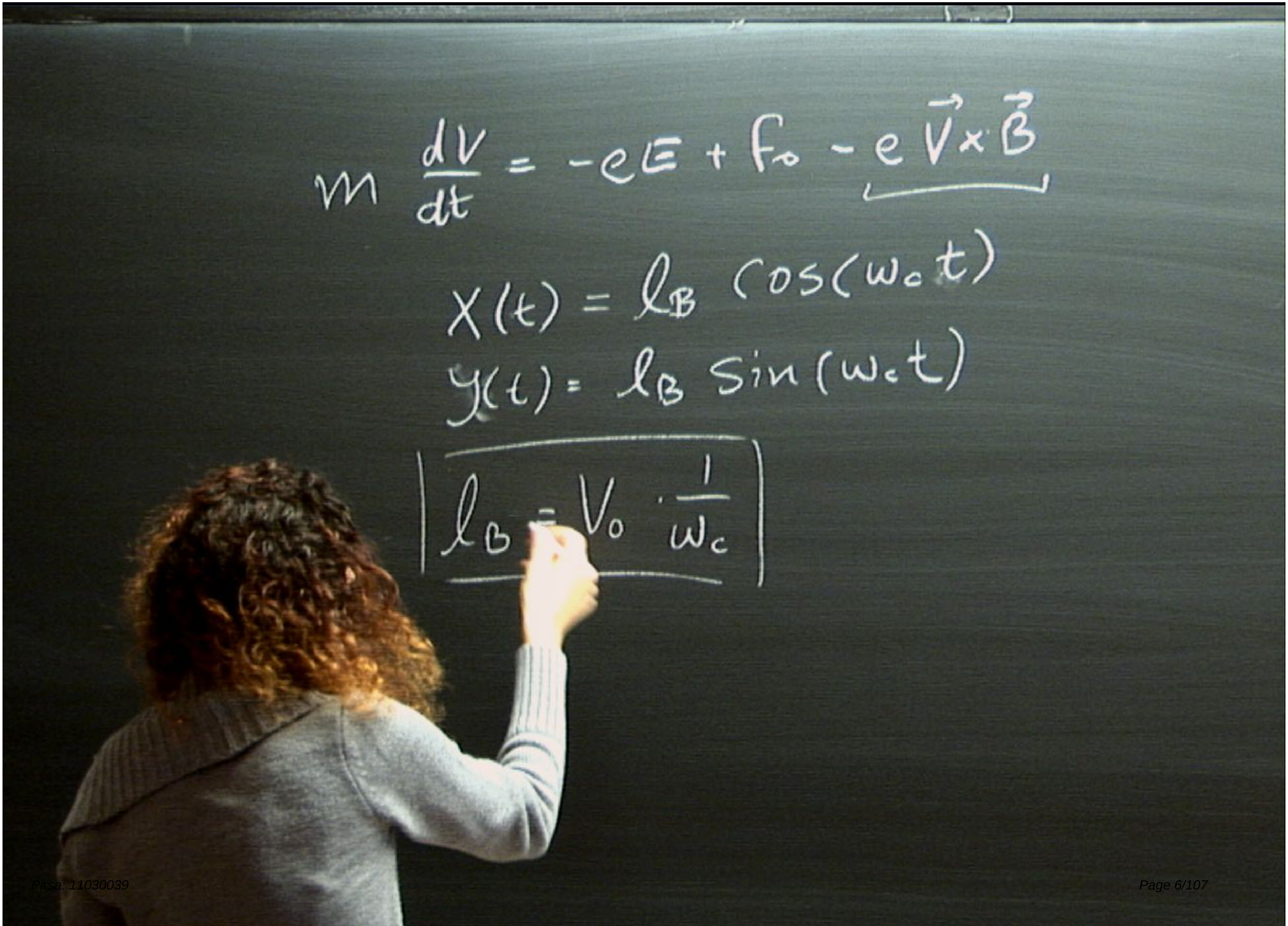
Abstract:

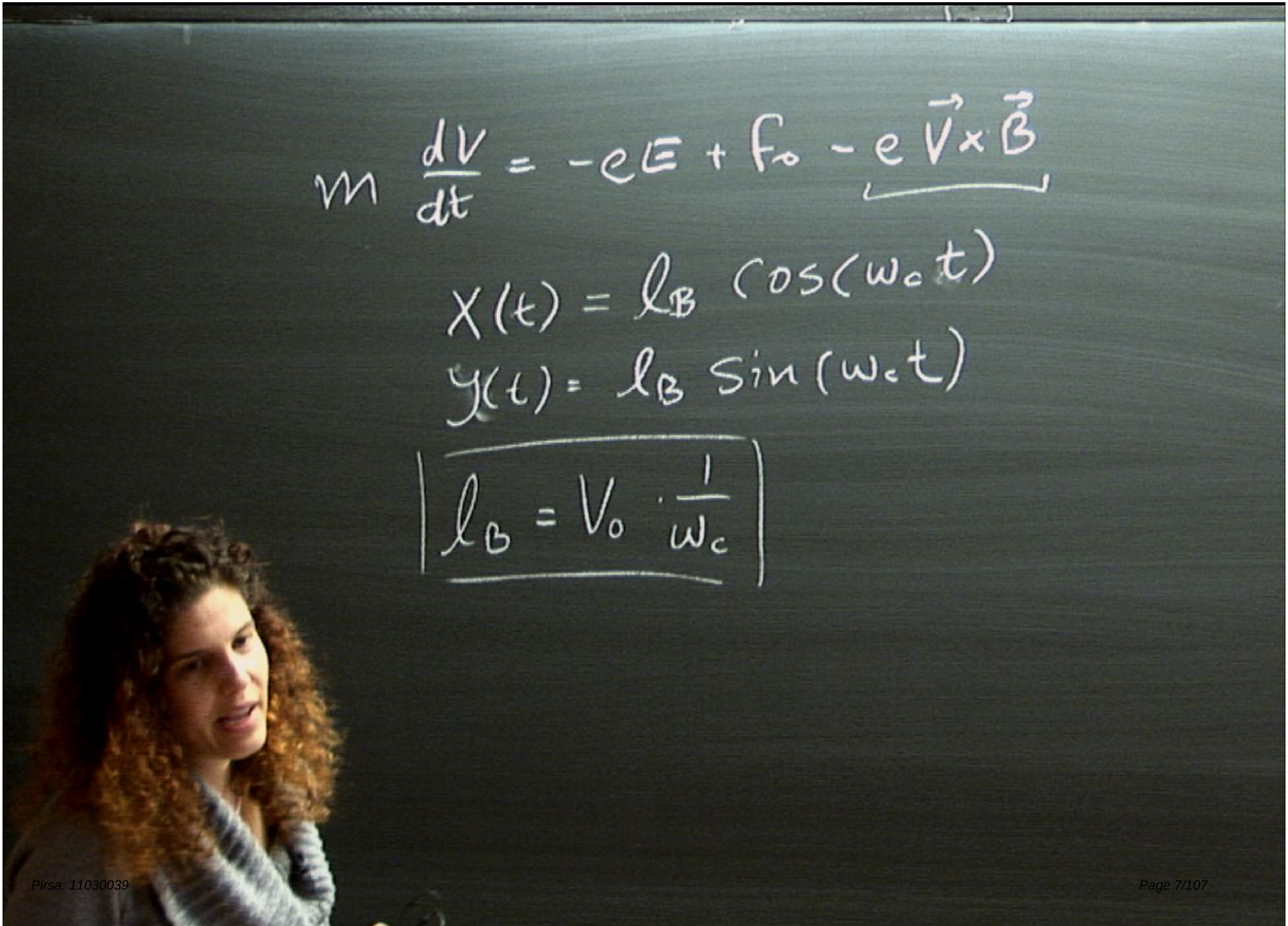
perimeter scholars
international

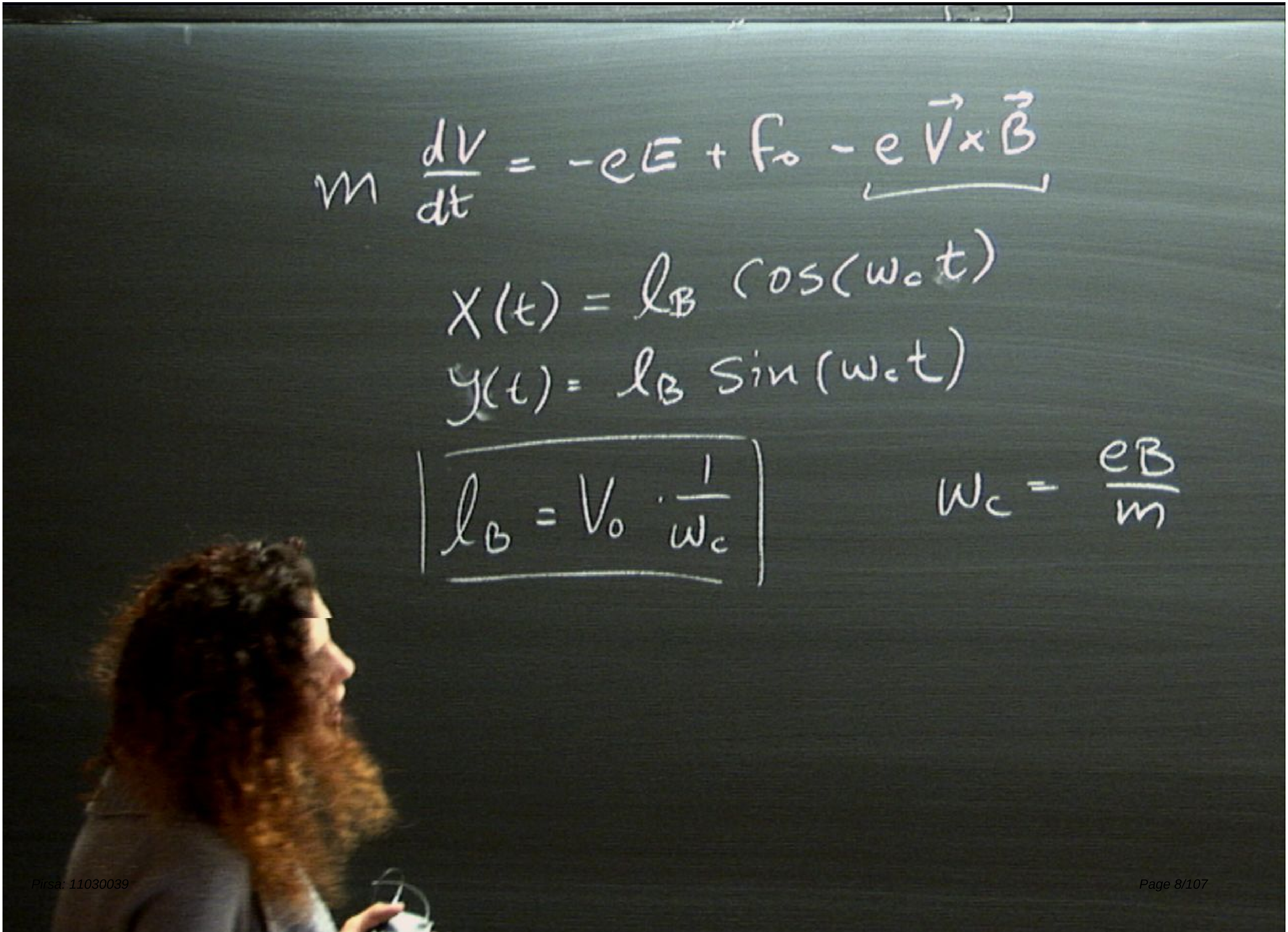

$m \frac{dV}{dt} = -eE + f_o$

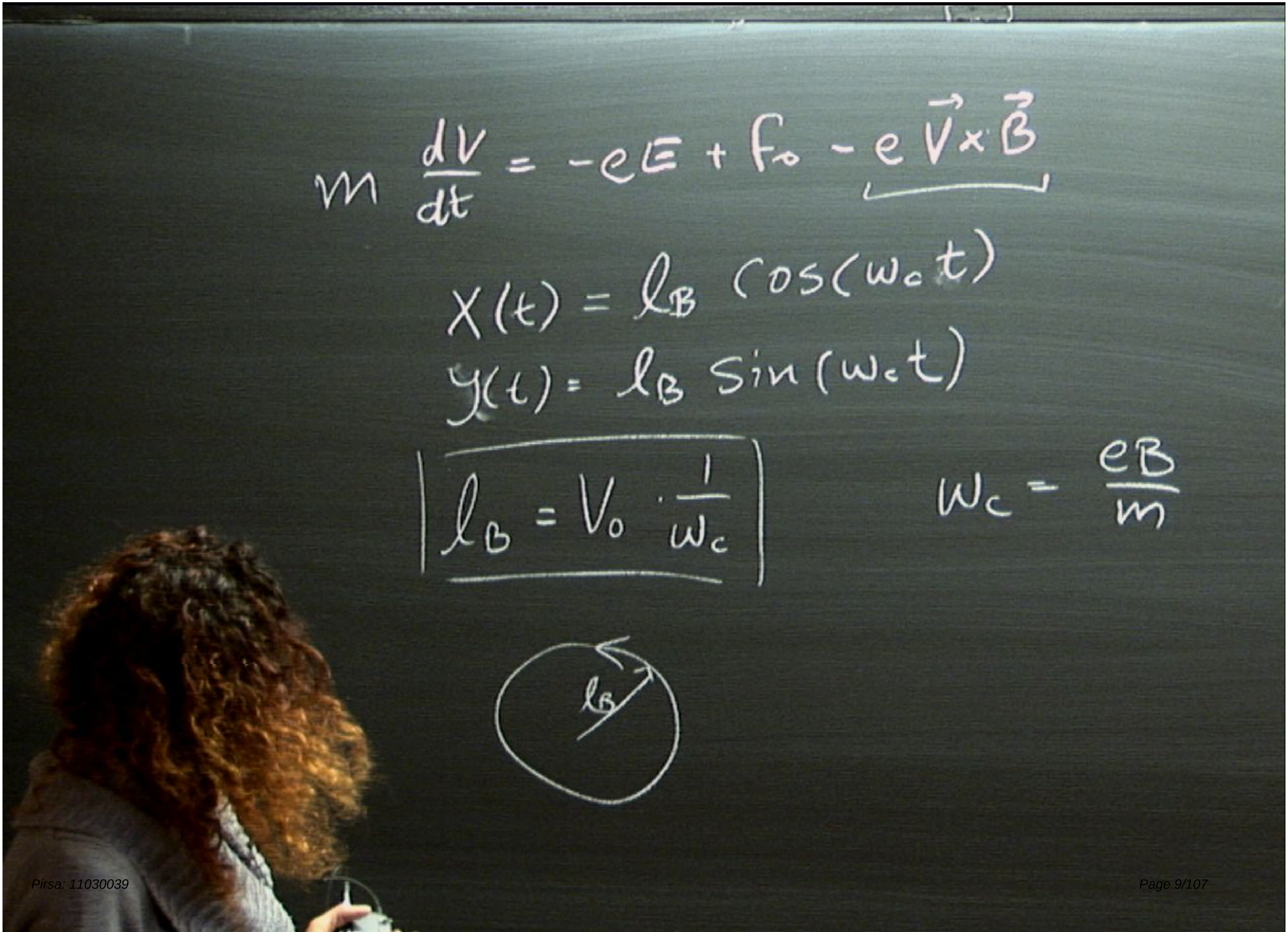

$m \frac{dV}{dt} = -eE + f_0 - e\vec{V} \times \vec{B}$
$X(t) = l_B$


$m \frac{dV}{dt} = -eE + f_0 - e\vec{V} \times \vec{B}$
$X(t) = l_B \cos(\omega_0 t)$
$y(t) = l_B \sin($


$m \frac{dV}{dt} = -eE + f_0 - e\vec{V}\times\vec{B}$
$x(t) = l_B \cos(\omega_c t)$
$y(t) = l_B \sin(\omega_c t)$
$l_B = V_0 \cdot \frac{1}{\omega_c}$


$m \frac{dV}{dt} = -eE + f_0 - e\vec{V} \times \vec{B}$
$X(t) = l_B \cos(\omega_c t)$
$y(t) = l_B \sin(\omega_c t)$
$l_B = V_0 \cdot \frac{1}{\omega_c}$


$m \frac{dV}{dt} = -eE + f_0 - e\vec{V} \times \vec{B}$
$x(t) = l_B \cos(\omega_c t)$
$y(t) = l_B \sin(\omega_c t)$
$l_B = V_0 \cdot \frac{1}{\omega_c}$
$\omega_c = \frac{eB}{m}$

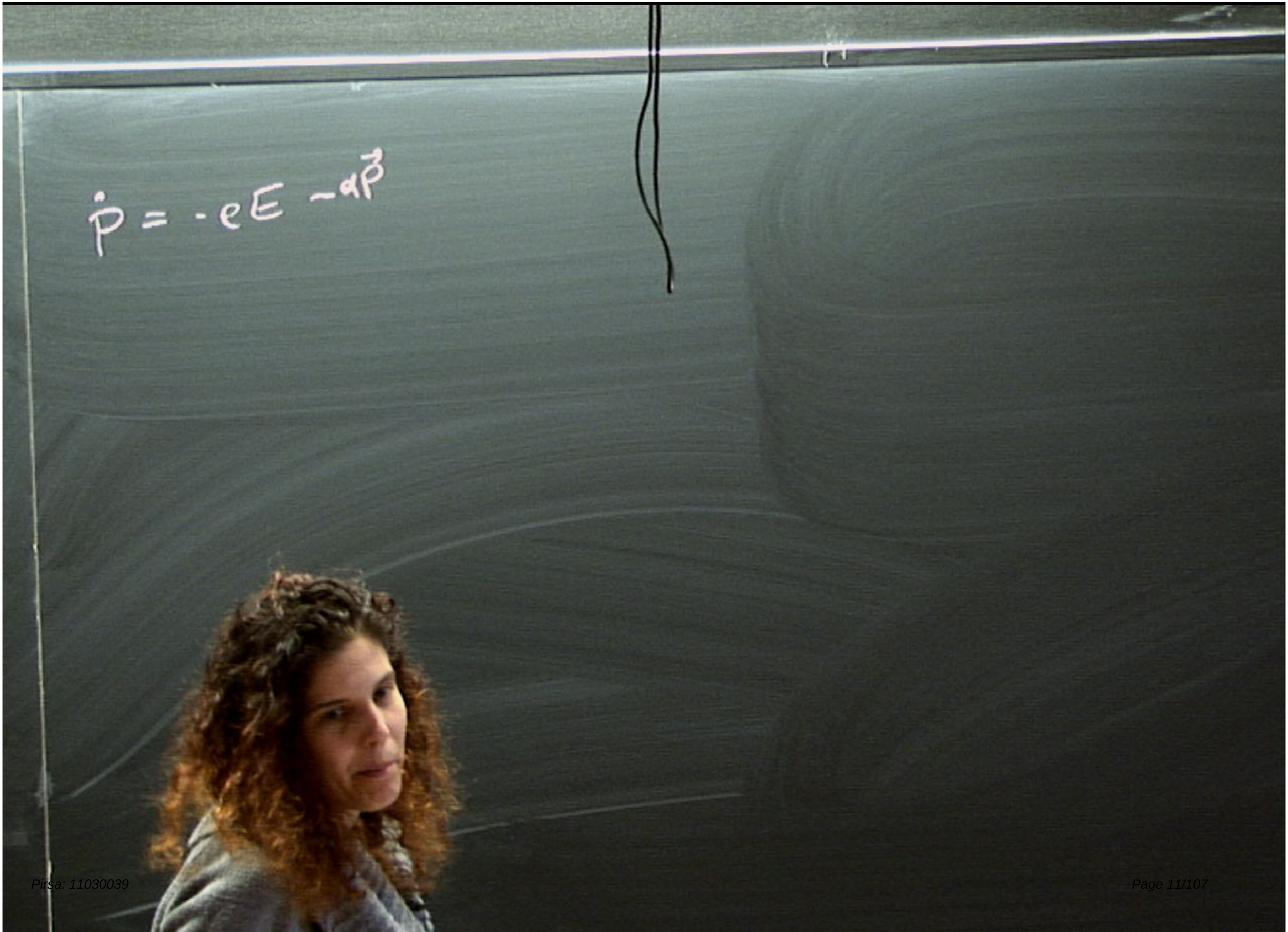

$m \frac{dV}{dt} = -eE + f_0 - e\vec{V} \times \vec{B}$
$X(t) = l_B \cos(\omega_c t)$
$y(t) = l_B \sin(\omega_c t)$
$l_B = V_0 \cdot \frac{1}{\omega_c}$
$\omega_c = \frac{eB}{m}$
l_B

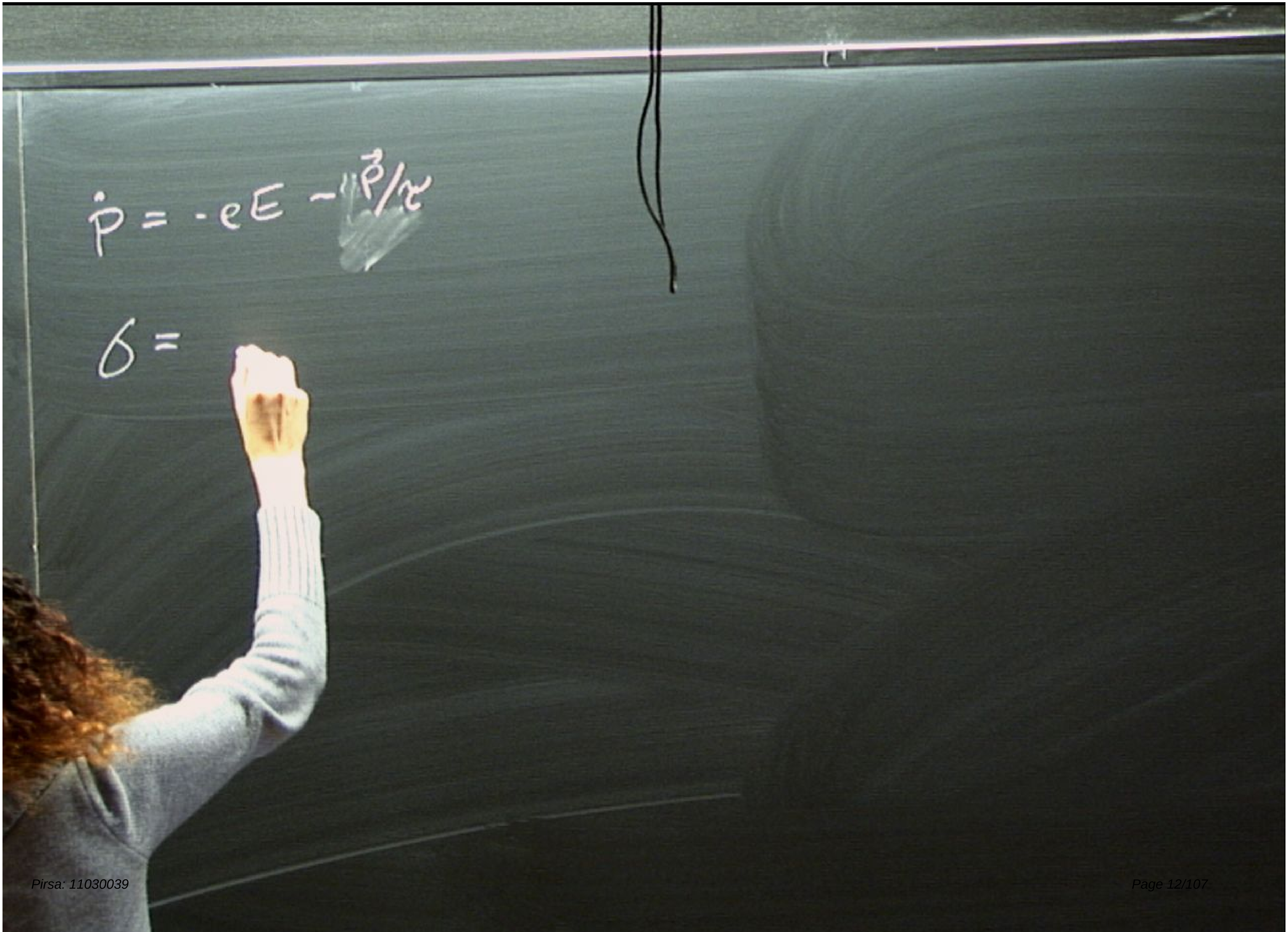
$$m \frac{dV}{dt} = -eE + f_0 - e\underbrace{\vec{V} \times \vec{B}}$$

$$x(t) = l_B \cos(\omega_c t)$$

$$y(t) = l_B \sin(\omega_c t)$$

$$\boxed{l_B = V_0 \cdot \frac{1}{\omega_c}} \qquad \omega_c = \frac{eB}{m}$$


$\dot{p} = -eE - \alpha\vec{p}$


ṗ = -eE − p⃗/τ
σ =

$$\dot{p} = -eE - \vec{p}/\tau$$

$$P(t)$$

$$\sigma = \frac{ne^2\tau}{m}$$

$$\dot{p} = -eE - \vec{p}/\tau$$

$$\sigma = \frac{ne^2\tau}{m}$$

$$P(t) = P_0 e^{-t/\tau} + eE$$

$$\dot{\vec{p}} = -\vec{p}/\tau$$

$$\dot{p} = -eE - \vec{p}/\tau$$

$$P(t) = P_0 e^{-t/\tau} + eE\tau$$

$$\sigma = \frac{ne^2\tau}{m}$$

$$\dot{\vec{p}} = -\vec{p}/\tau$$

$$J = \frac{e}{m}\langle p\rangle n$$

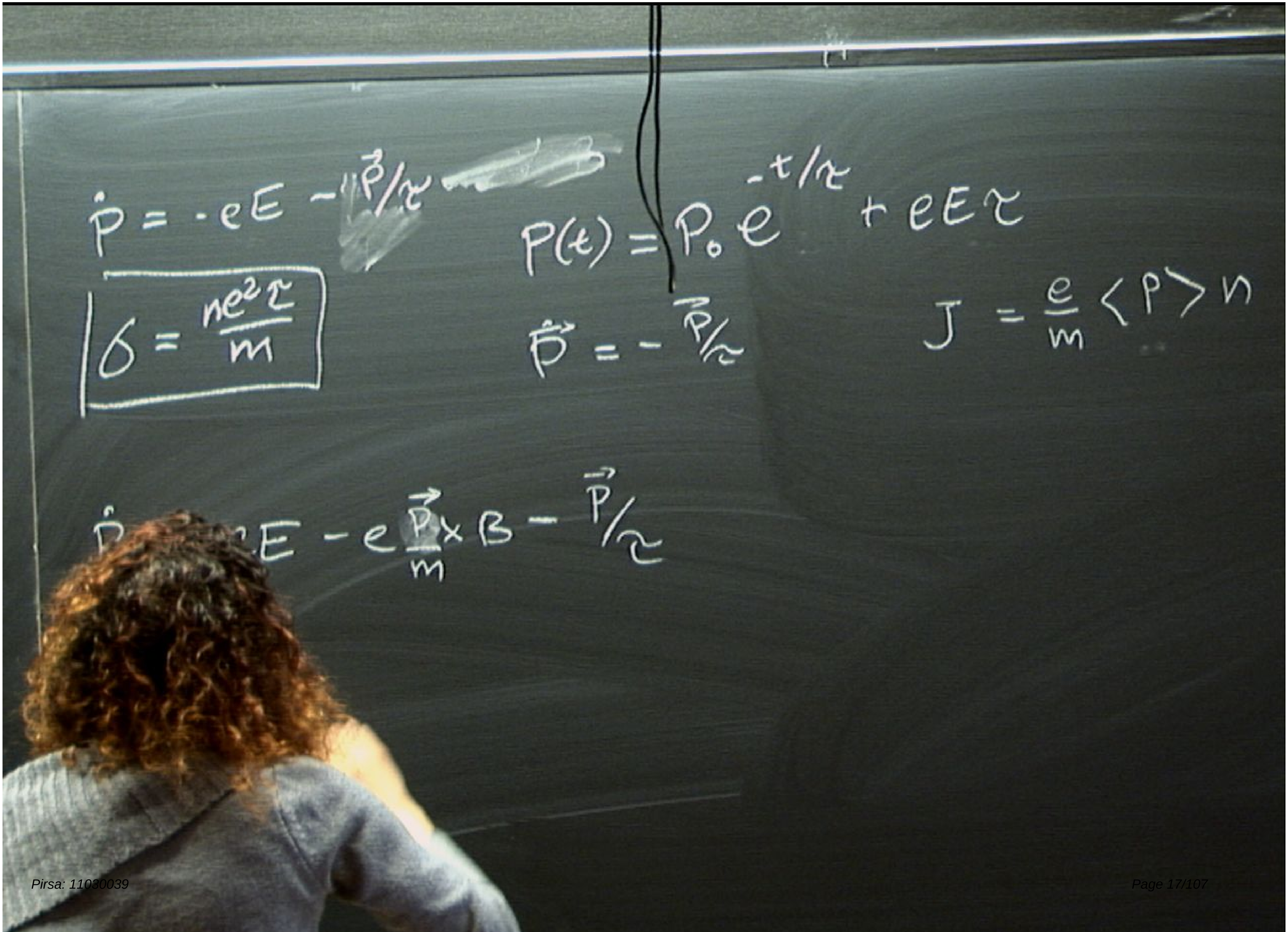
$$\dot{p} = -eE - \vec{p}/\tau$$

$$\boxed{\sigma = \frac{ne^2\tau}{m}}$$

$$P(t) = P_0\, e^{-t/\tau} + eE\tau$$

$$\dot{\vec{p}} = -\vec{p}/\tau$$

$$J = \frac{e}{m}\langle p \rangle n$$


$\dot{p} = -eE - \vec{p}/\tau$
$P(t) = P_0 e^{-t/\tau} + eE\tau$
$\sigma = \frac{ne^2\tau}{m}$
$\dot{\vec{p}} = -\vec{p}/\tau$
$J = \frac{e}{m}\langle p \rangle n$
$E - e\frac{\vec{p}}{m} \times B - \vec{p}/\tau$

$$\dot{p} = -eE - \vec{p}/\tau$$

$$P(t) = P_0 e^{-t/\tau} + eE\tau$$

$$\boxed{\sigma = \frac{ne^2\tau}{m}}$$

$$\dot{\vec{p}} = -\vec{p}/\tau$$

$$J = \frac{e}{m}\langle p \rangle n$$

$$\dot{p} = -eE - eB\frac{\vec{p}}{m}\times\hat{z} - \vec{p}/\tau = -eE - \omega_c\,\vec{p}\times\hat{z} - \frac{1}{\tau}\vec{p}$$

$$\dot{p} = -eE - \vec{p}/\tau$$

$$P(t) = P_0 e^{-t/\tau} + eE\tau$$

$$\boxed{\sigma = \frac{ne^2\tau}{m}}$$

$$\dot{\vec{p}} = -\vec{p}/\tau$$

$$J = \frac{e}{m}\langle p \rangle n$$

$$\dot{p} = -eE - eB\frac{\vec{p}}{m} \times \hat{z} - \vec{p}/\tau = -eE_x - w_c\,\vec{p} \times \hat{z} - \frac{1}{\tau}\vec{p}$$

$$\dot{p}_x =$$

$$\dot{p} = -eE - \vec{p}/\tau$$

$$P(t) = P_0 e^{-t/\tau} + eE\tau$$

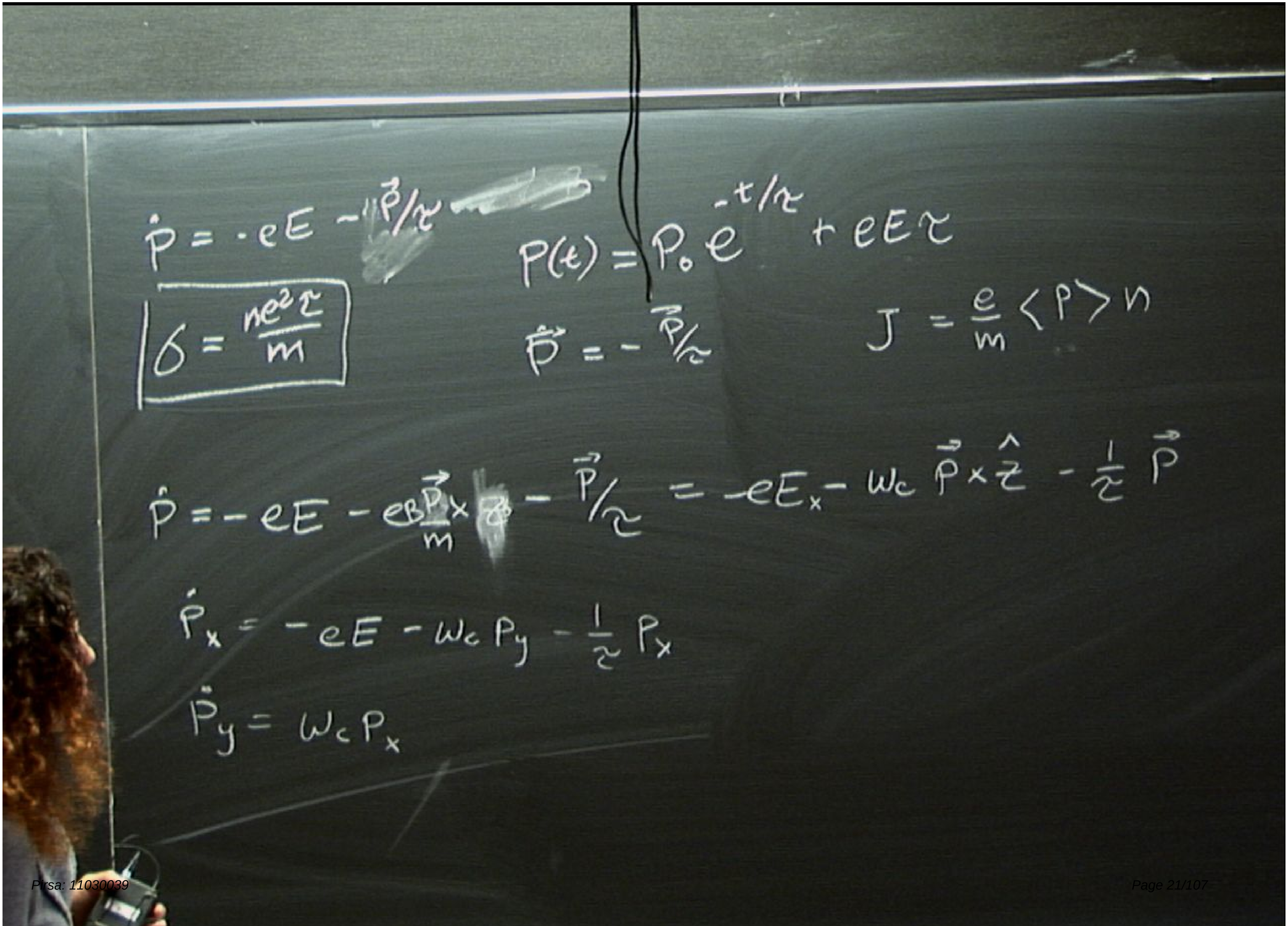
$$\boxed{\sigma = \frac{ne^2\tau}{m}}$$

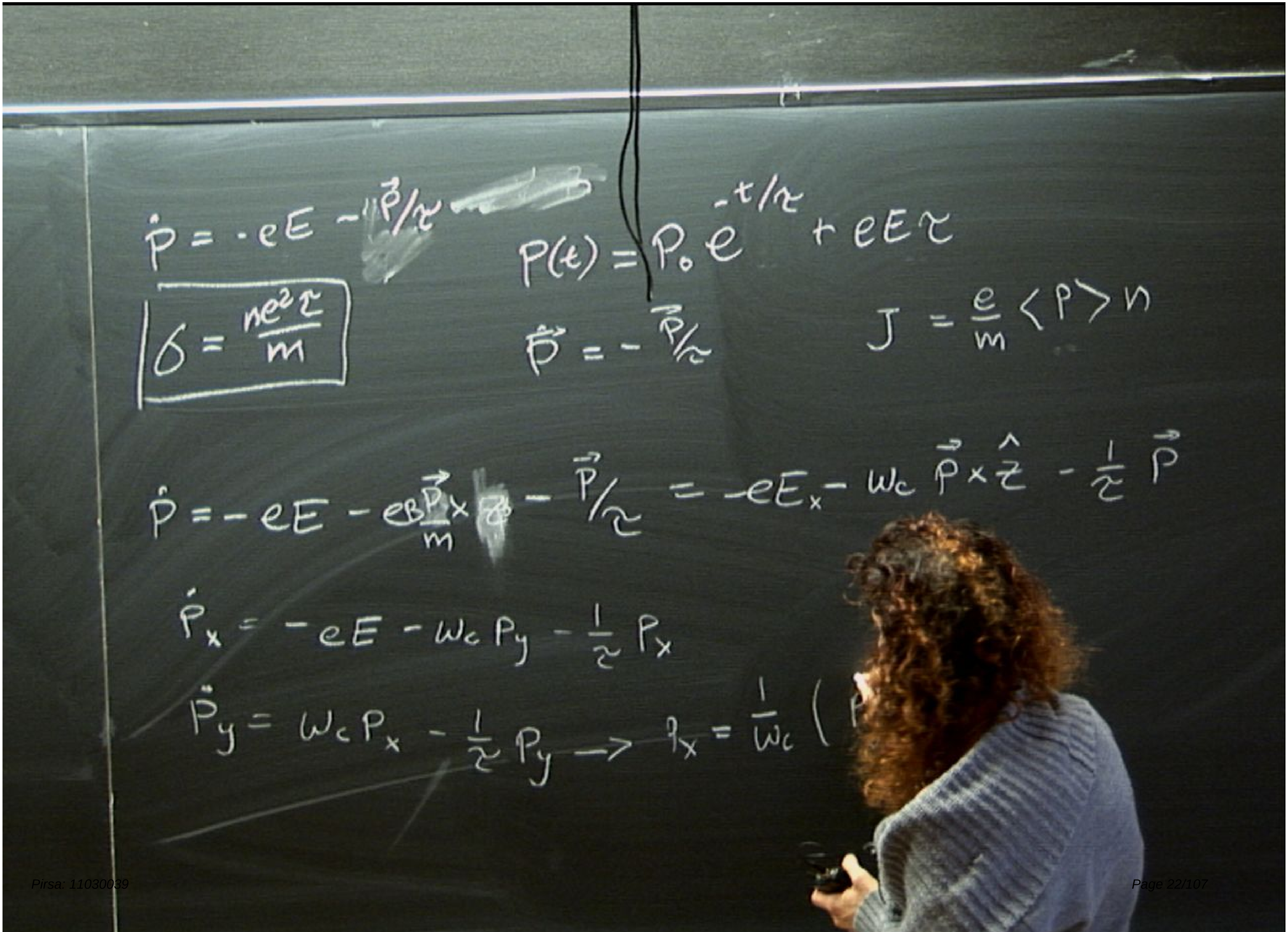
$$\dot{\vec{p}} = -\vec{p}/\tau$$

$$J = \frac{e}{m}\langle p \rangle n$$

$$\dot{p} = -eE - eB\frac{\vec{p}}{m}\times \hat{z} - \vec{p}/\tau = -eE_x - \omega_c \vec{p}\times\hat{z} - \frac{1}{\tau}\vec{p}$$

$$\dot{p}_x = -eE - \omega_c p_y - \frac{1}{\tau}p_x$$


$\dot{P} = -eE - \vec{P}/\tau$
$P(t) = P_0 e^{-t/\tau} + eE\tau$
$\sigma = \frac{ne^2\tau}{m}$
$\dot{\vec{P}} = -\vec{P}/\tau$
$J = \frac{e}{m} \langle P \rangle n$
$\dot{P} = -eE - \frac{eB}{m}\vec{P} \times \hat{z} - \vec{P}/\tau = -eE_x - \omega_c \vec{P} \times \hat{z} - \frac{1}{\tau}\vec{P}$
$\dot{P}_x = -eE - \omega_c P_y - \frac{1}{\tau} P_x$
$\dot{P}_y = \omega_c P_x$


ṗ = -eE - p⃗/τ
P(t) = P₀ e^(-t/τ) + eEτ
σ = ne²τ / m
p⃗̇ = - p⃗/τ
J = (e/m) ⟨p⟩ n
ṗ = -eE - eB p⃗/m × ẑ - p⃗/τ = -eEₓ - ω_c p⃗ × ẑ - (1/τ) p⃗
ṗₓ = -eE - ω_c p_y - (1/τ) pₓ
ṗ_y = ω_c pₓ - (1/τ) p_y → pₓ = (1/ω_c) (

$$\dot{p} = -eE - \vec{p}/\tau$$

$$P(t) = P_0 e^{-t/\tau} + eE\tau$$

$$\boxed{\sigma = \frac{ne^2\tau}{m}}$$

$$\dot{\vec{p}} = -\vec{p}/\tau \qquad J = \frac{e}{m}\langle p \rangle n$$

$$\dot{p} = -eE - eB\frac{\vec{P}}{m}\times \hat{z} - \vec{P}/\tau = -eE_x - \omega_c \vec{P}\times\hat{z} - \frac{1}{\tau}\vec{P}$$

1) $\dot{P}_x = -eE - \omega_c P_y - \frac{1}{\tau}P_x$

2) $\dot{P}_y = \omega_c P_x - \frac{1}{\tau}P_y \longrightarrow P_x = \frac{1}{\omega_c}\left(\dot{P}_y + \frac{1}{\tau}P_y\right)$

2→1) $\frac{1}{\omega_c}\left(\ddot{P}_y + \frac{1}{\tau}\dot{P}_y\right) = -eE - \omega_c P_y - \frac{1}{\tau\omega_c}\left(\dot{P}_y + \frac{1}{\tau}P_y\right)$

$$\dot{p} = -eE - \vec{p}/\tau$$

$$\boxed{\sigma = \frac{ne^2\tau}{m}}$$

$$P(t) = P_0 e^{-t/\tau} + eE\tau$$

$$\dot{\vec{p}} = -\vec{p}/\tau$$

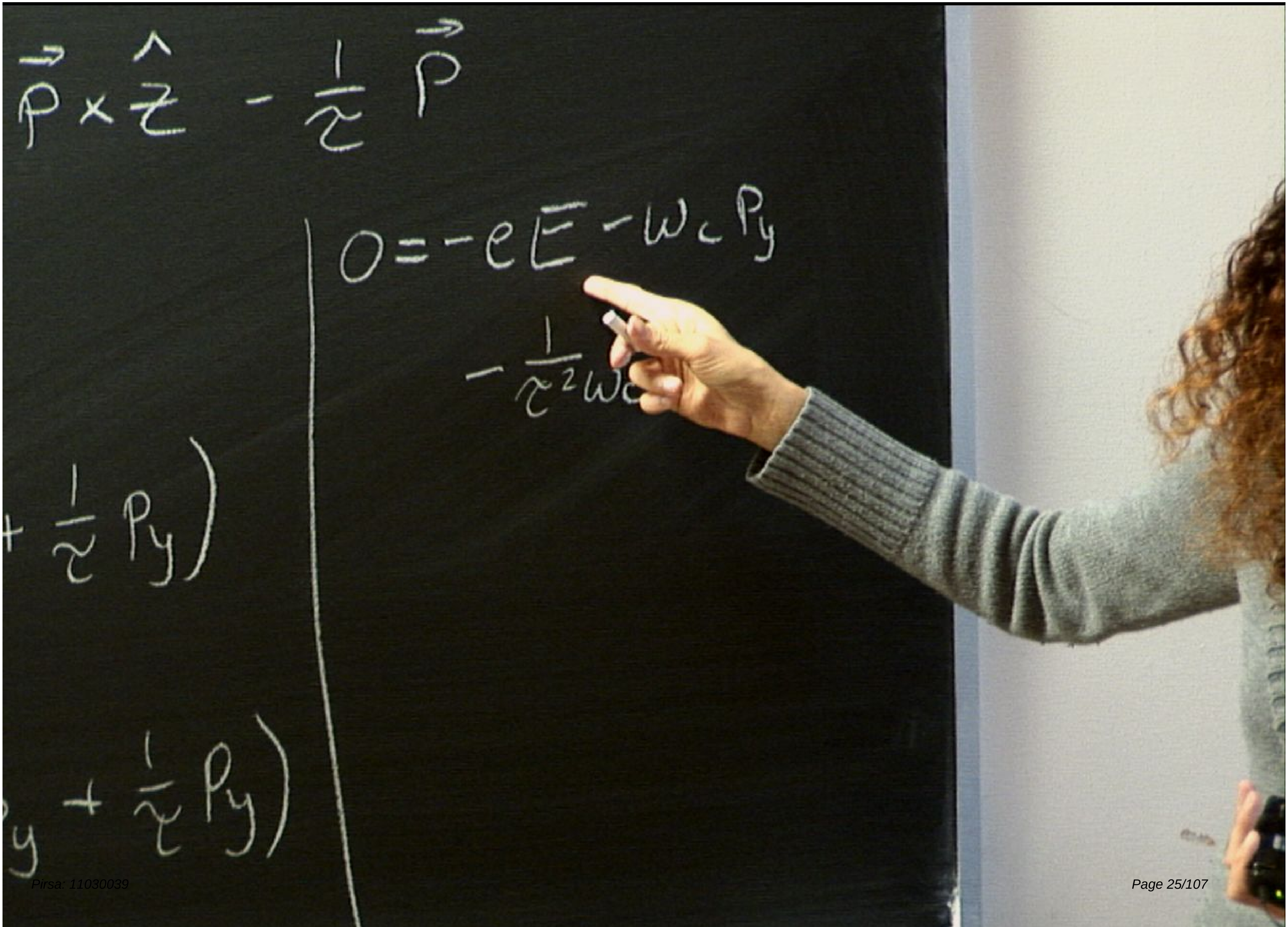
$$J = \frac{e}{m}\langle p \rangle n$$

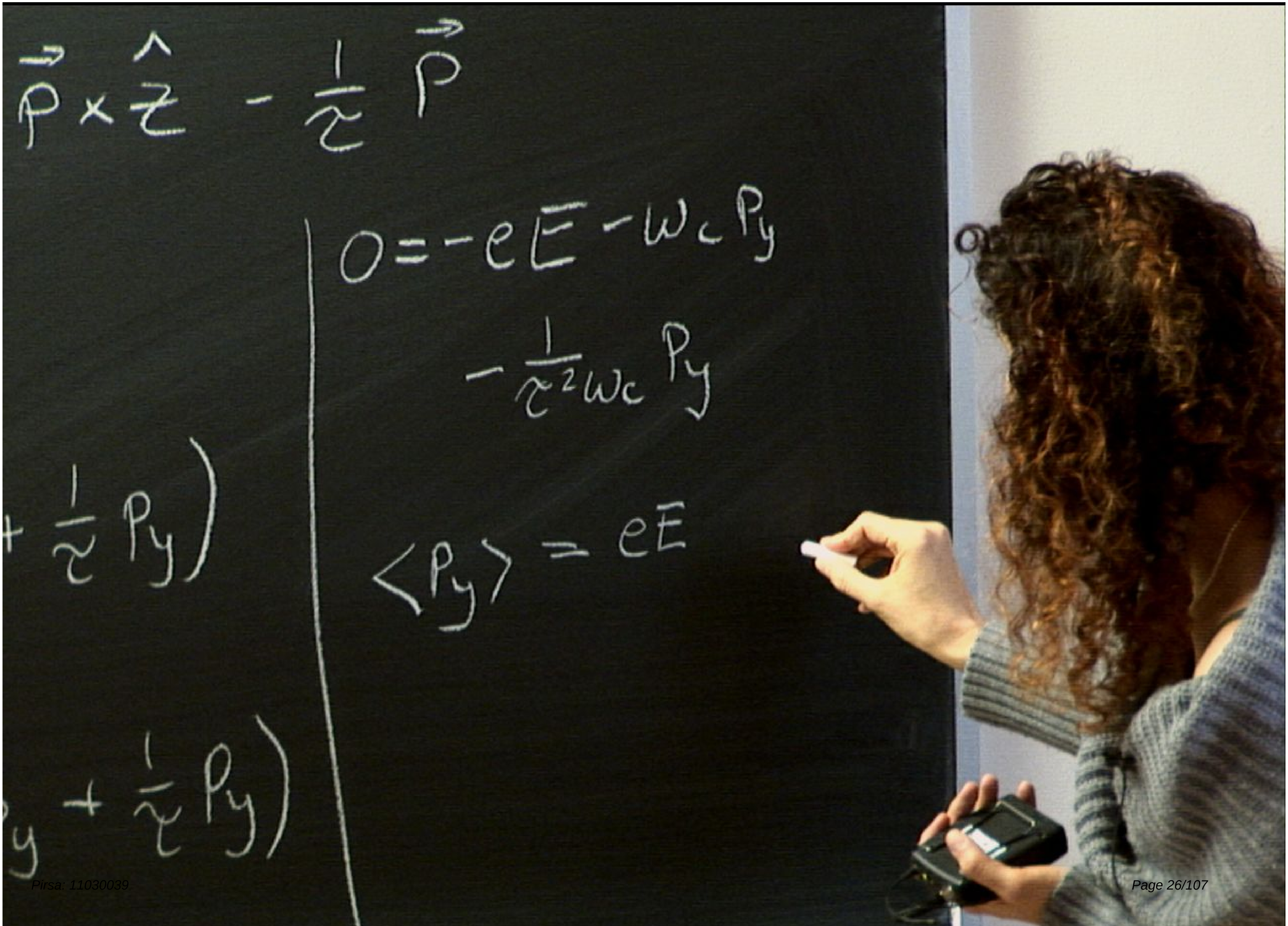
$$\dot{p} = -eE - \frac{eB}{m}\vec{p}\times\hat{z} - \vec{p}/\tau = -eE_x - \omega_c \vec{p}\times\hat{z} - \frac{1}{\tau}\vec{p}$$

1) $\dot{p}_x = -eE - \omega_c p_y - \frac{1}{\tau}p_x$

2) $\dot{p}_y = \omega_c p_x - \frac{1}{\tau}p_y \longrightarrow p_x = \frac{1}{\omega_c}\left(\dot{p}_y + \frac{1}{\tau}p_y\right)$

2→1) $\frac{1}{\omega_c}\left(\ddot{p}_y + \frac{1}{\tau}\dot{p}_y\right) = -eE - \omega_c p_y - \frac{1}{\tau\omega_c}\left(\dot{p}_y + \frac{1}{\tau}p_y\right)$


O = -eE - w_c P_y


P⃗ × ẑ − 1/τ P⃗
0 = −eE − ω_c P_y
− 1/(τ²ω_c) P_y
+ 1/τ P_y)
⟨P_y⟩ = eE
y + 1/τ P_y)

$\vec{P} \times \hat{z} - \frac{1}{\tau} \vec{P}$

$+ \frac{1}{\tau} P_y \Big)$

$0 = -eE - \omega_c P_y$

$- \frac{1}{\tau^2 \omega_c} P_y$

$\langle P_y \rangle = eE \left(\omega + \frac{1}{\tau^2 \omega_c} \right)^{-1}$

$_y + \frac{1}{\tau} P_y \Big)$

$$\vec{p} \times \hat{z} - \frac{1}{\tau} \vec{p}$$

$$+ \frac{1}{\tau} p_y \Big)$$

$$_y + \frac{1}{\tau} p_y \Big)$$

$$0 = -eE - \omega_c p_y - \frac{1}{\tau^2 \omega_c} p_y$$

$$\langle p_y \rangle = eE \left(\omega + \frac{1}{\tau^2 \omega_c} \right)^{-1}$$

$$\sigma_{xy} = \frac{ne^2\tau}{m} \frac{\omega_c \tau}{1 + \omega_c^2 \tau^2}$$

$$\vec{p} \times \hat{z} - \frac{1}{\tau} \vec{p}$$

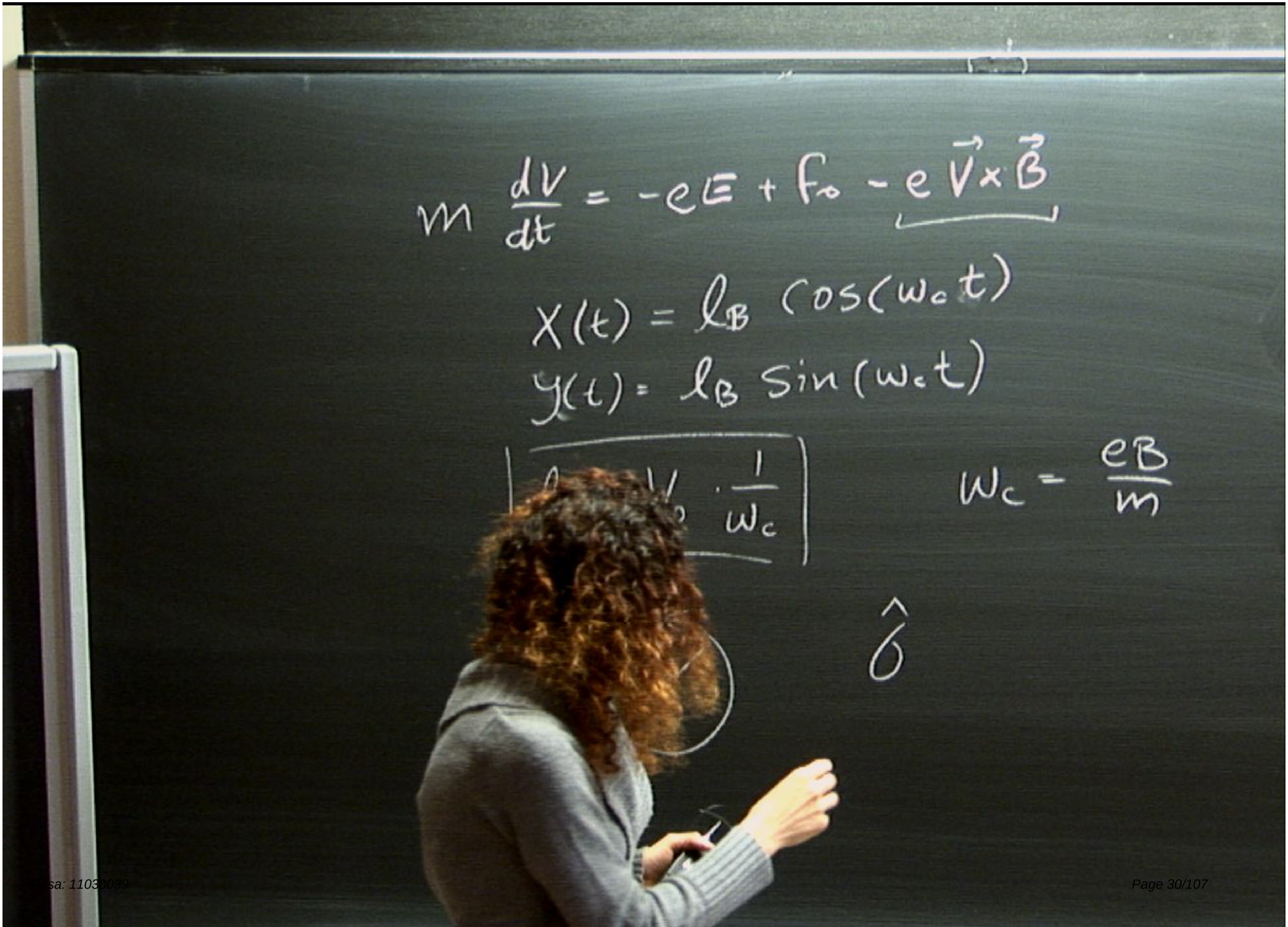
$$+ \frac{1}{\tau} p_y)$$

$$p_y + \frac{1}{\tau} p_y)$$

$$0 = -eE - \omega_c p_y - \frac{1}{\tau^2 \omega_c} p_y$$

$$\langle p_y \rangle = eE \left(\omega + \frac{1}{\tau^2 \omega_c} \right)^{-1}$$

$$\sigma_{xy} = \frac{n e^2 \tau}{m} \frac{\omega_c \tau}{1 + \omega_c^2 \tau^2}$$


m dV/dt = -eE + f0 - e V × B
X(t) = lB cos(wc t)
y(t) = lB sin(wc t)
wc = eB/m

$$m \frac{dV}{dt} = -eE + f_0 - e\vec{V}\times\vec{B}$$

$$x(t) = l_B \cos(\omega_c t)$$

$$y(t) = l_B \sin(\omega_c t)$$

$$l_B = V_0 \cdot \frac{1}{\omega_c}$$

$$\omega_c = \frac{eB}{m}$$

$$\hat{\sigma} = \frac{ne^2\tau}{m} \cdot \frac{1}{1+\omega_c^2\tau^2}\begin{pmatrix} 1 & \omega_c\tau \\ -\omega_c\tau & 1 \end{pmatrix}$$

$\dot{p} = -$

$\sigma = n$

$\dot{p} = -$

1) $\dot{p}_x =$

2) $\dot{p}_y =$

2→1) $\frac{1}{\omega_c}$

$$m\frac{dV}{dt} = -eE + f_0 - e\vec{V}\times\vec{B}$$

$$x(t) = l_B \cos(\omega_c t)$$

$$y(t) = l_B \sin(\omega_c t)$$

$$l_B = V_0 \cdot \frac{1}{\omega_c}$$

$$\omega_c = \frac{eB}{m}$$

$$\hat{\sigma} = \frac{ne^2\tau}{m}\cdot\frac{1}{1+\omega_c^2\tau^2}\begin{pmatrix} 1 & \omega_c\tau \\ -\omega_c\tau & 1 \end{pmatrix}$$

$\dot{p} = -$ …

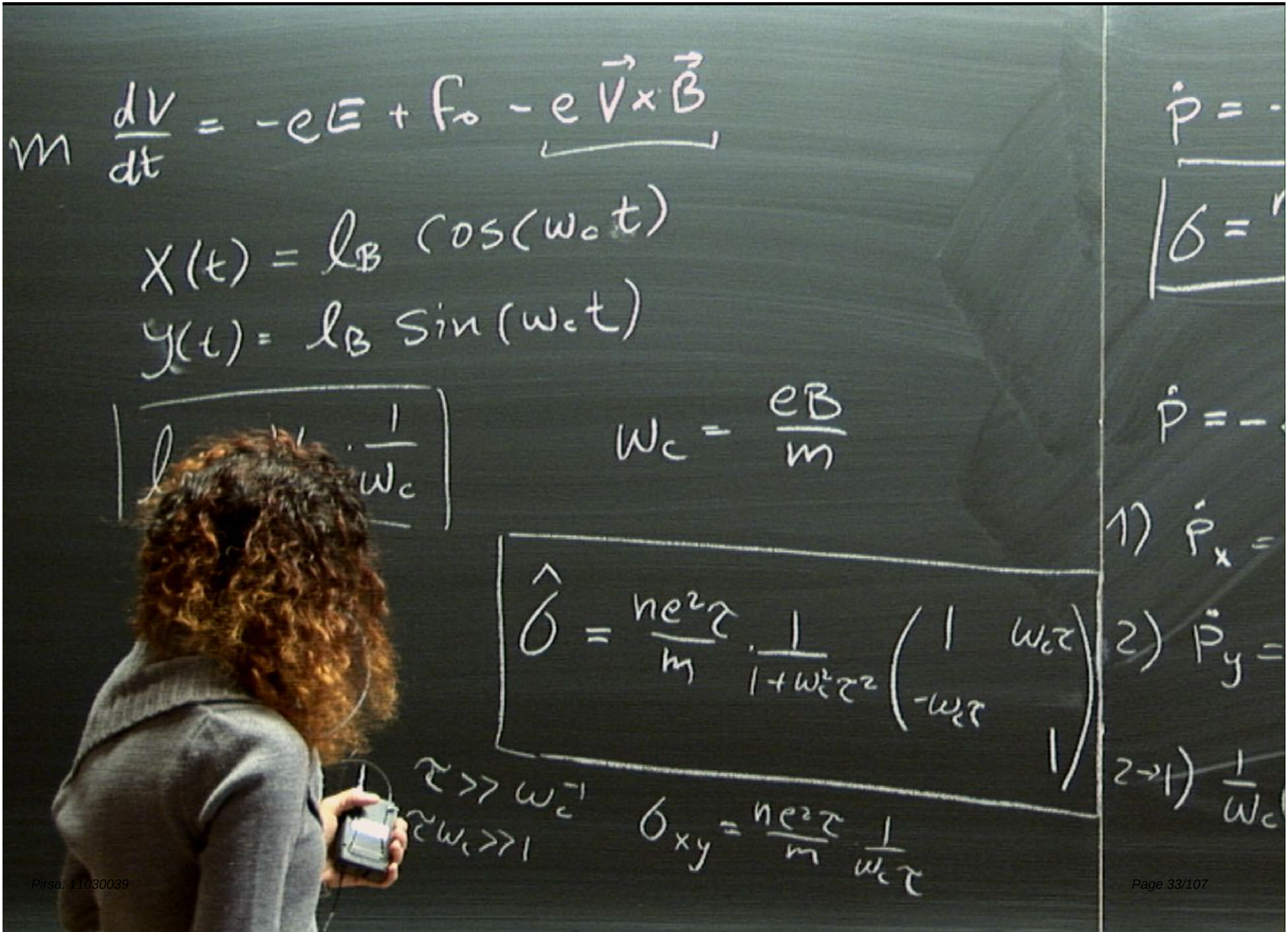
$\sigma =$ …

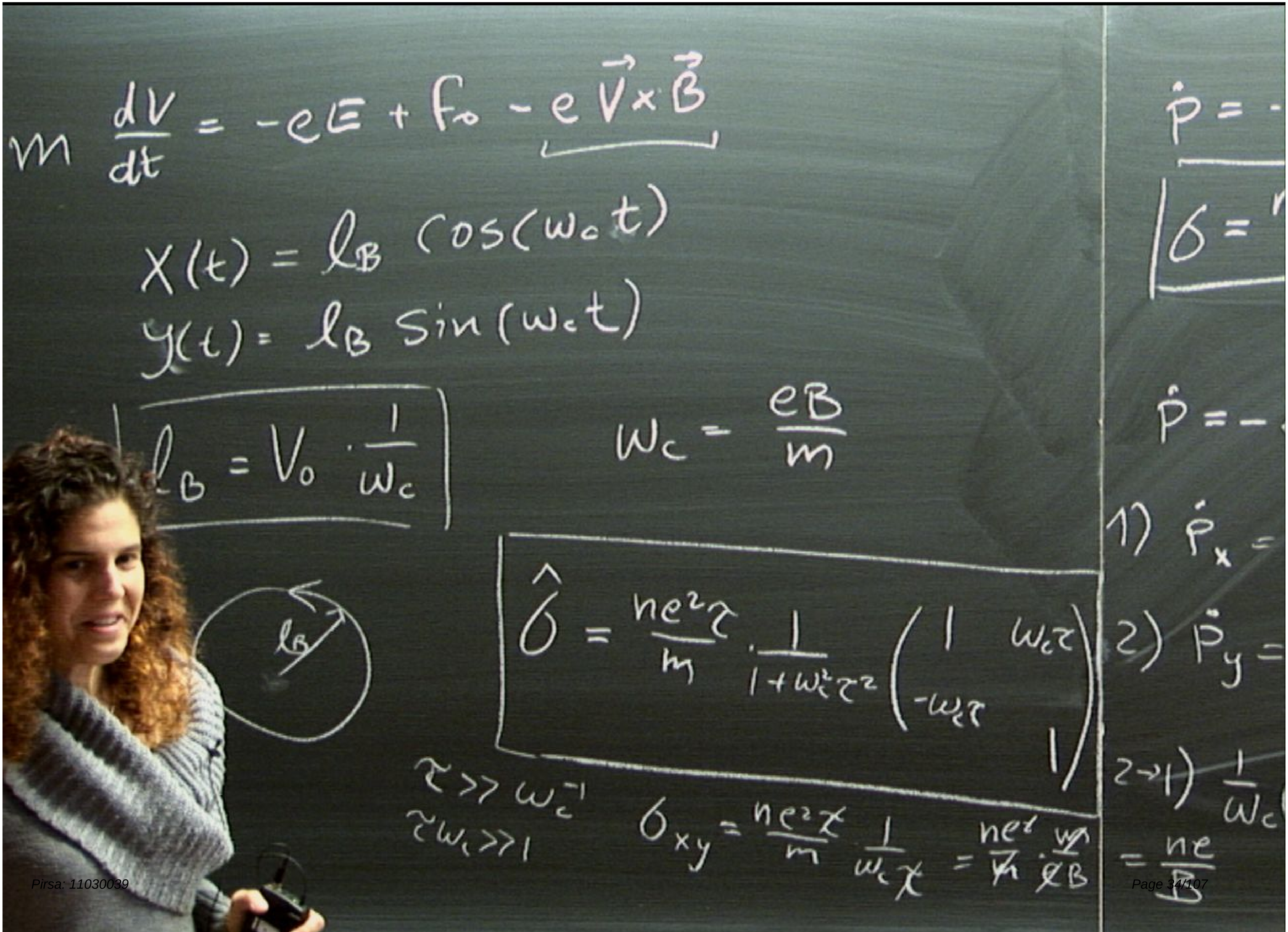
$\dot{P} = -$ …

1) $\dot{P}_x =$ …

2) $\dot{P}_y =$ …

2→1) $\frac{1}{\omega_c}$ …


m dV/dt = -eE + f₀ - e V⃗ × B⃗
X(t) = l_B cos(ω_c t)
y(t) = l_B sin(ω_c t)
ω_c = eB/m
σ̂ = ne²τ/m · 1/(1+ω_c²τ²) (1 ω_cτ; -ω_cτ 1)
τ >> ω_c⁻¹
τω_c >> 1
σ_xy = ne²τ/m · 1/(ω_cτ)


m dV/dt = -eE + f₀ - e V⃗ × B⃗
x(t) = l_B cos(w_c t)
y(t) = l_B sin(w_c t)
l_B = V₀ · 1/w_c
w_c = eB/m
l_B
σ̂ = ne²τ/m · 1/(1+w_c²τ²) (1 w_cτ; -w_cτ 1)
τ >> w_c⁻¹
τw_c >> 1
σ_xy = ne²τ/m · 1/(w_c τ) = ne²/m · m/(eB)
= ne/B
1) ṗ_x =
2) ṗ_y =
2→1) 1/w_c

$$m\frac{dV}{dt} = -eE + f_0 - e\vec{V}\times\vec{B}$$

$$x(t) = l_B\cos(\omega_c t)$$

$$y(t) = l_B\sin(\omega_c t)$$

$$l_B = V_0\cdot\frac{1}{\omega_c} \qquad \omega_c = \frac{eB}{m}$$

$$\hat{\sigma} = \frac{ne^2\tau}{m}\cdot\frac{1}{1+\omega_c^2\tau^2}\begin{pmatrix}1 & \omega_c\tau\\ -\omega_c\tau & 1\end{pmatrix}$$

$\tau \gg \omega_c^{-1}$

$\tau\omega_c \gg 1$

$$\sigma_{xy} = \frac{ne^2\tau}{m}\,\frac{1}{\omega_c\tau} = \frac{ne^2}{m}\cdot\frac{m}{eB} = \frac{ne}{B}$$

$\dot{P} = -$ …

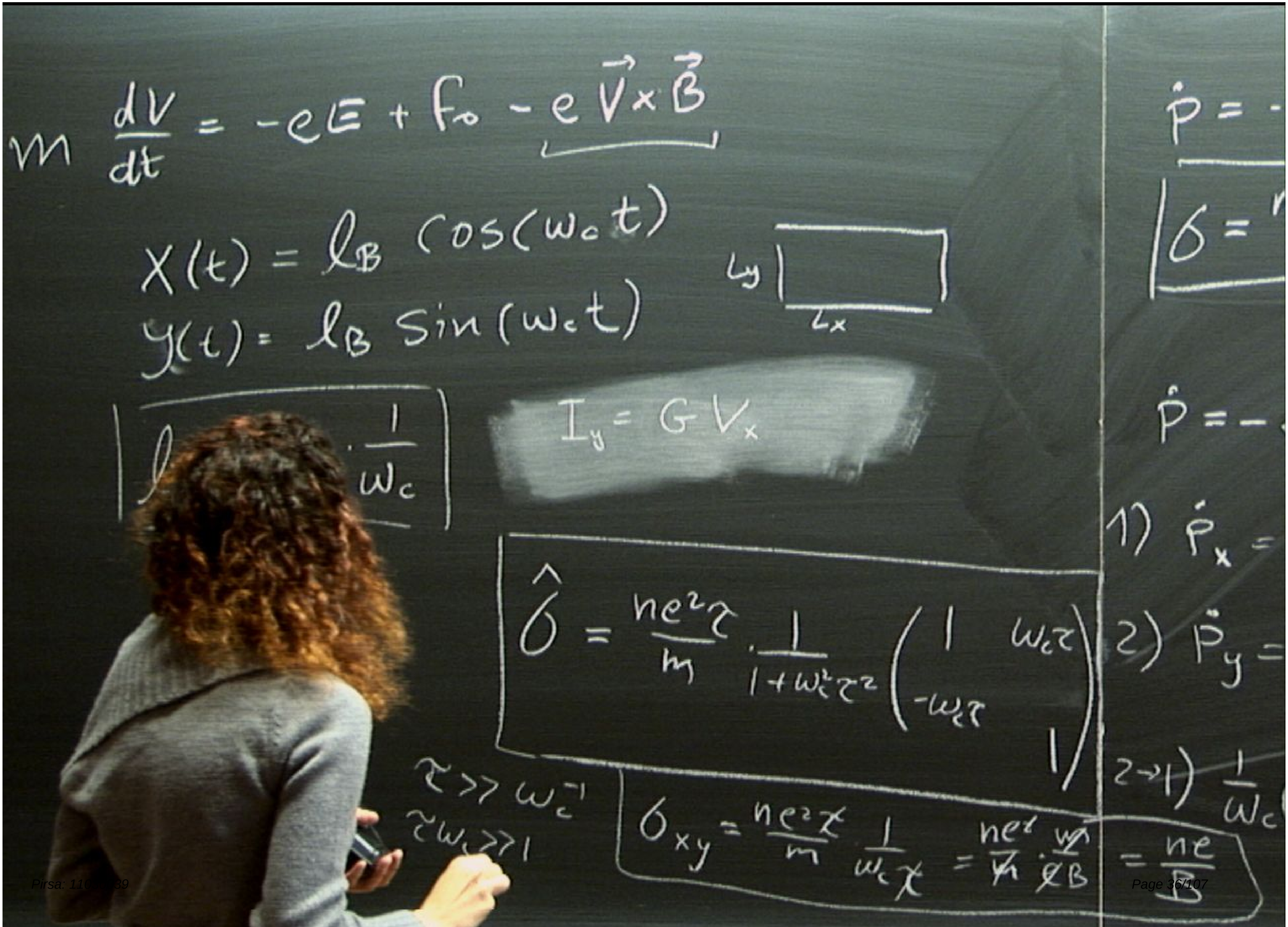
$\sigma =$ …

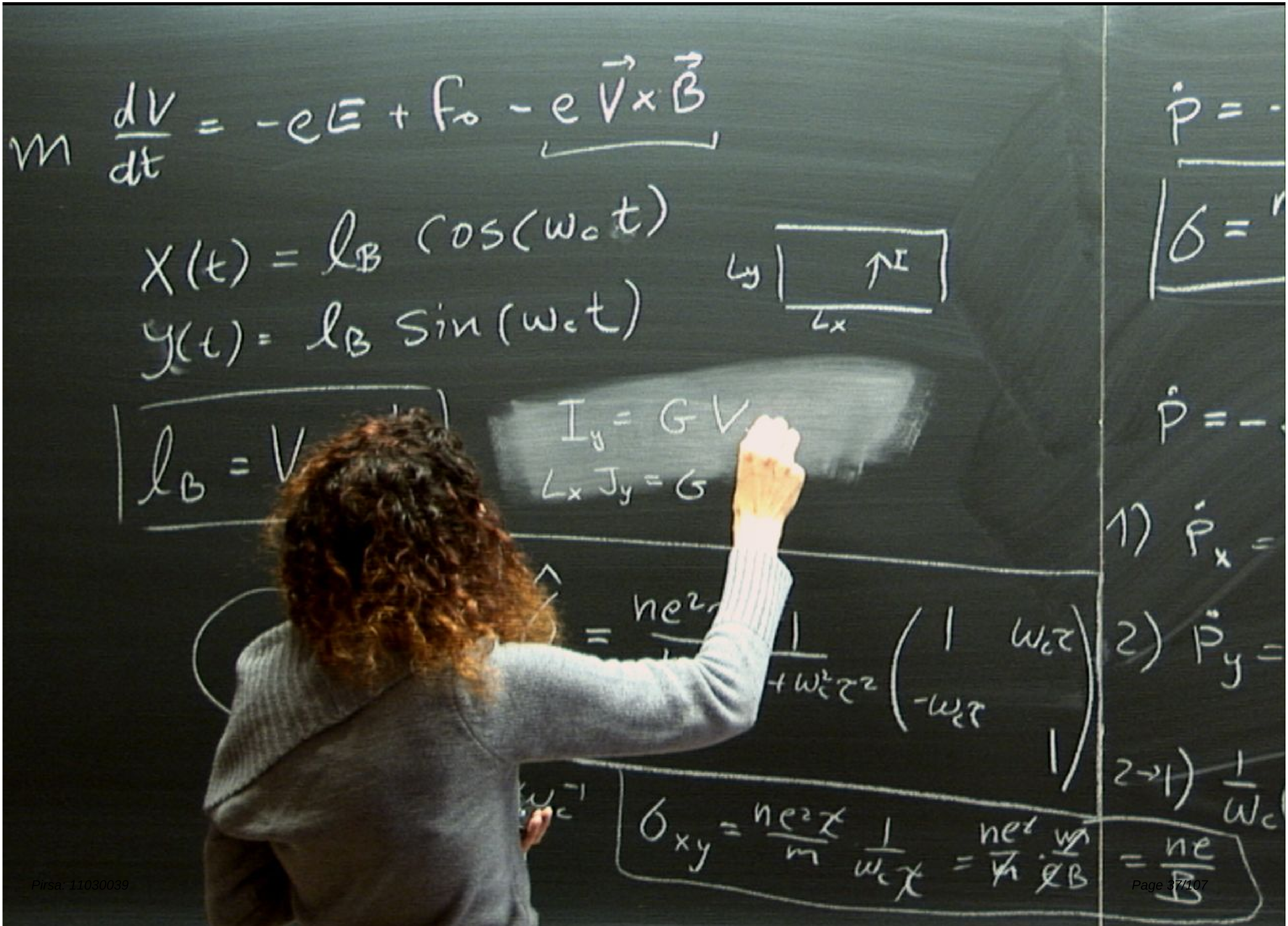
$\dot{P} = -$ …

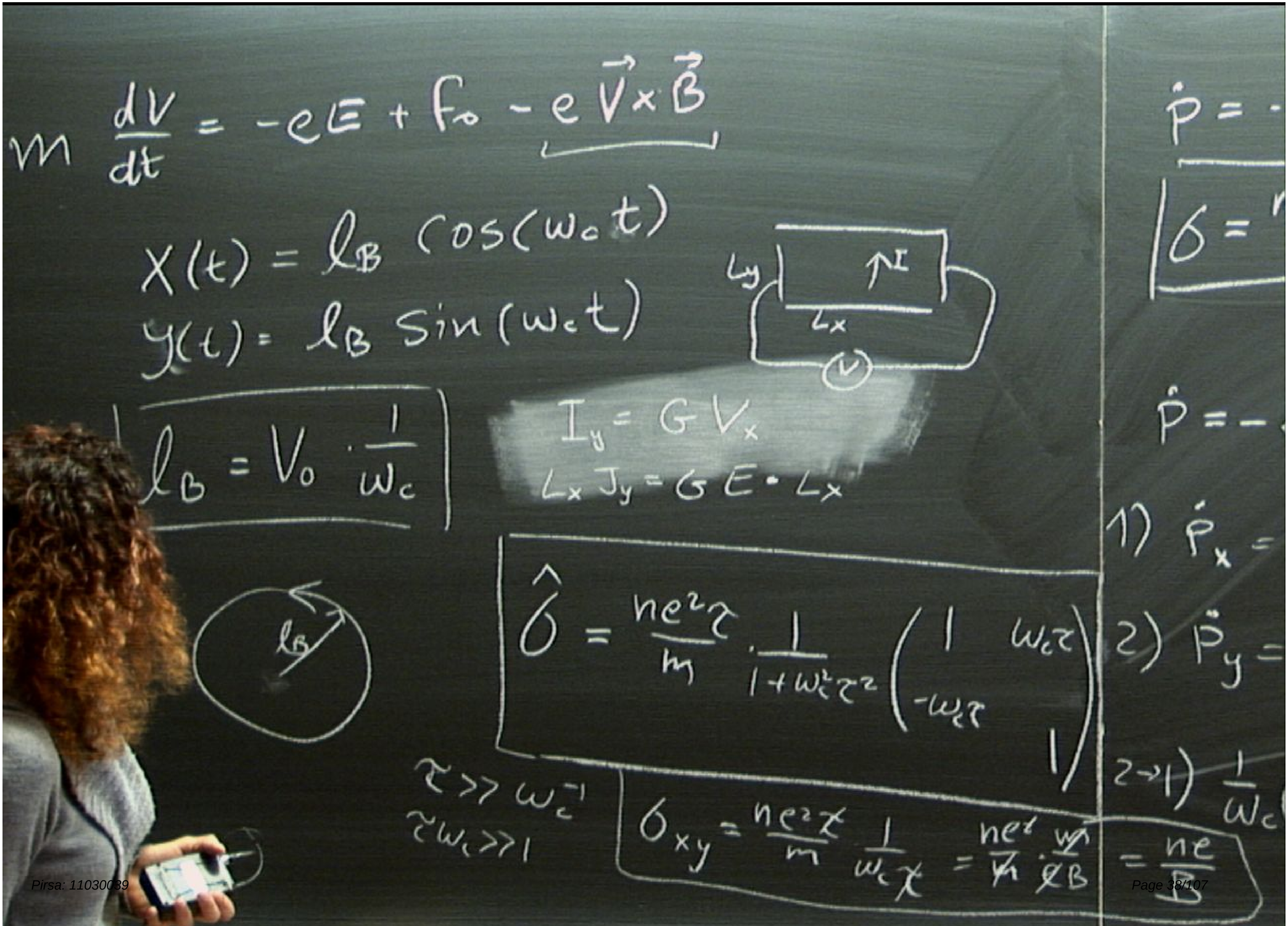
1) $\dot{P}_x =$ …

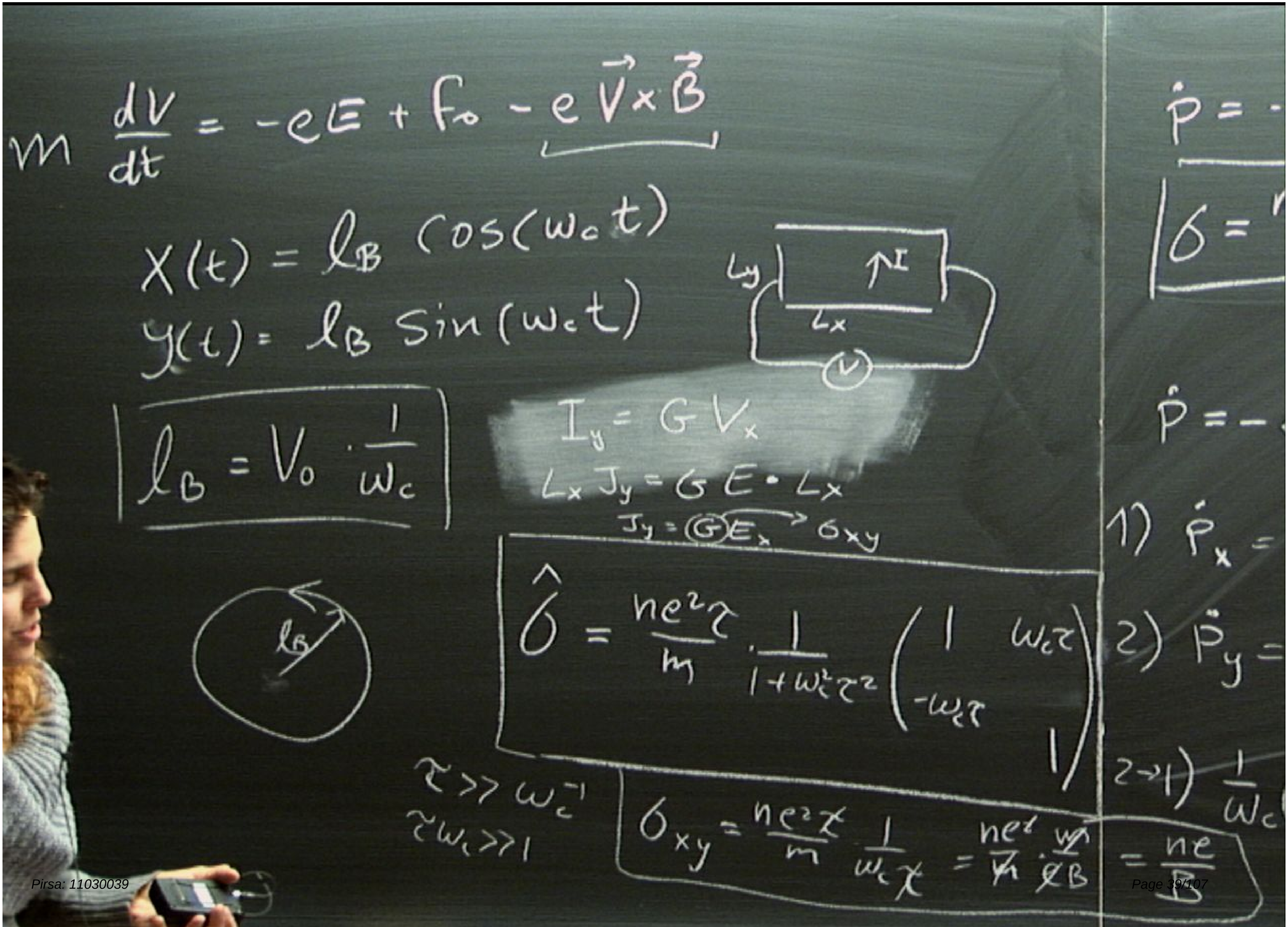
2) $\dot{P}_y =$ …

$2\to1)$ $\frac{1}{\omega_c}$ …


m dV/dt = -eE + f0 - e V × B
X(t) = lB cos(wc t)
y(t) = lB sin(wc t)
Ly
Lx
Iy = G Vx
σ = ne²τ/m · 1/(1+wc²τ²)
τ >> wc⁻¹
τwc >> 1
σxy = ne²τ/m · 1/(wcτ) = ne/B
P =
σ =


m dV/dt = -eE + f₀ - e V⃗ × B⃗
X(t) = l_B cos(ω_c t)
y(t) = l_B sin(ω_c t)
l_B = V
I_y = G V
L_x J_y = G
L_y
L_x
I
1+ω_c²τ²
1 ω_cτ
-ω_cτ 1
σ_xy = ne²τ/m · 1/(ω_c τ) = ne²/m · m/(eB) = ne/B
ω_c⁻¹
1) P_x =
2) P_y =
2→1) 1/ω_c

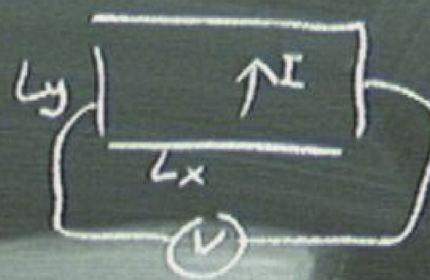

m dV/dt = -eE + f₀ - e V⃗ × B⃗
X(t) = l_B cos(ω_c t)
y(t) = l_B sin(ω_c t)
l_B = V₀ · 1/ω_c
L_y
I
L_x
V
I_y = G V_x
L_x J_y = G E · L_x
l_B
σ̂ = ne²τ/m · 1/(1+ω_c²τ²) (1 ω_cτ; -ω_cτ 1)
τ >> ω_c⁻¹
τω_c >> 1
σ_xy = ne²τ/m · 1/(ω_cτ) = ne²/m · m/(eB) = ne/B
ṗ =
σ =
ṗ =
1) ṗ_x =
2) ṗ_y =
2→1) 1/ω_c


m dV/dt = -eE + f₀ - e V⃗ × B⃗
x(t) = l_B cos(ω_c t)
y(t) = l_B sin(ω_c t)
l_B = V₀ · 1/ω_c
L_y
I
L_x
V
I_y = G V_x
L_x J_y = G E · L_x
J_y = G E_x → σ_xy
l_B
σ̂ = ne²τ/m · 1/(1+ω_c²τ²) (1 ω_cτ ; -ω_cτ 1)
τ >> ω_c⁻¹
τω_c >> 1
σ_xy = ne²τ/m · 1/(ω_c τ) = ne²/m · m/(eB) = ne/B
ṗ =
σ =
ṗ =
1) ṗ_x =
2) ṗ_y =
2→1) 1/ω_c

$$m\frac{dV}{dt} = -eE + f_0 - e\vec{V}\times\vec{B}$$

$$x(t) = l_B \cos(\omega_c t)$$

$$y(t) = l_B \sin(\omega_c t)$$



$$\boxed{l_B = V_0 \cdot \frac{1}{\omega_c}}$$

$$I_y = G V_x$$

$$L_x J_y = G E \cdot L_x$$

$$J_y = G E_x \rightarrow \sigma_{xy}$$

$$\hat{\sigma} = \frac{ne^2\tau}{m}\cdot\frac{1}{1+\omega_c^2\tau^2}\begin{pmatrix} 1 & \omega_c\tau \\ -\omega_c\tau & 1 \end{pmatrix}$$

$$\tau \gg \omega_c^{-1}$$

$$\tau\omega_c \gg 1$$

$$\sigma_{xy} = \frac{ne^2\tau}{m}\frac{1}{\omega_c\tau} = \frac{ne^2}{m}\cdot\frac{m}{eB} = \frac{ne}{B}$$

$\dot{p} = -$ ...

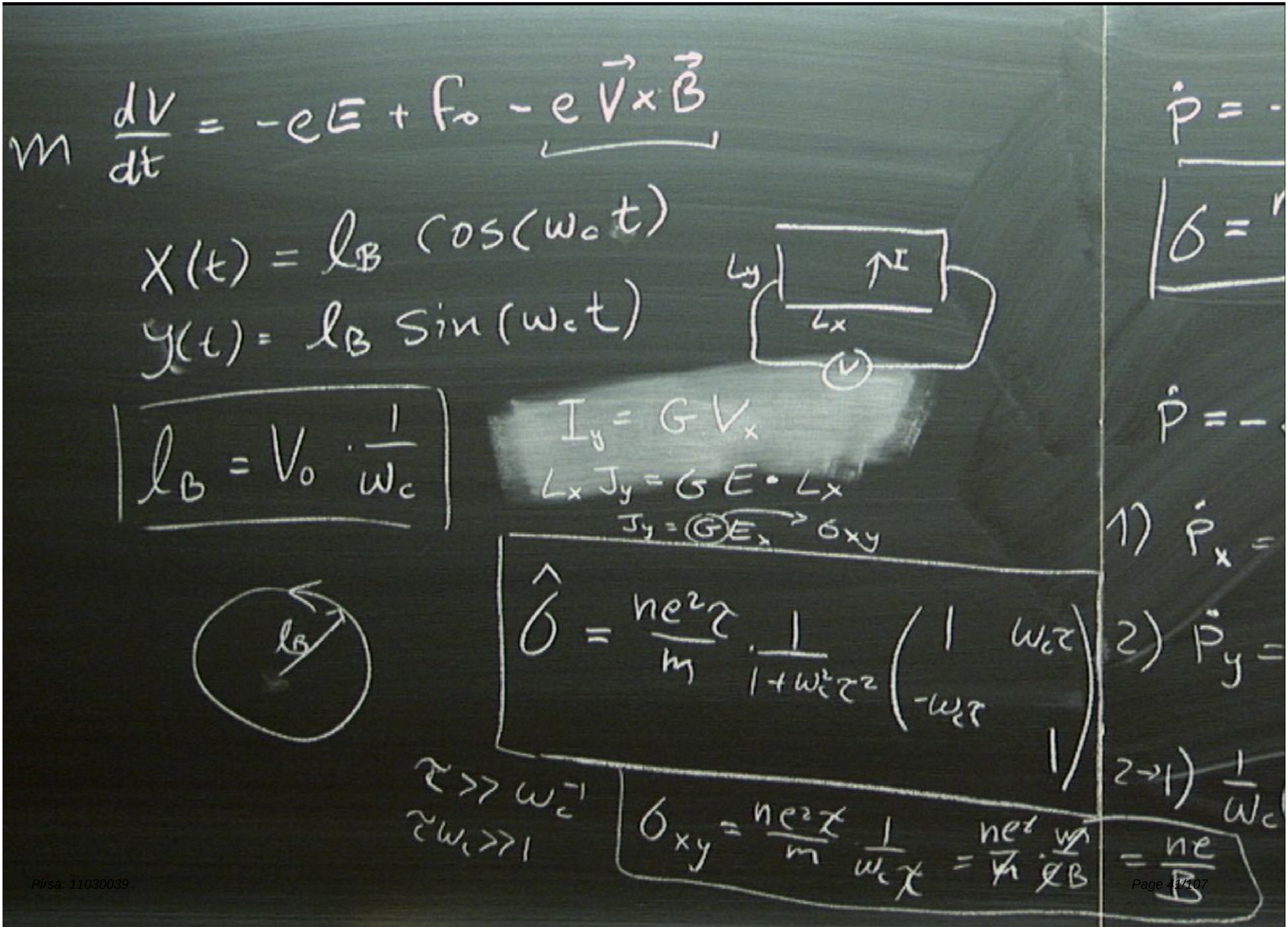
$\sigma =$ ...

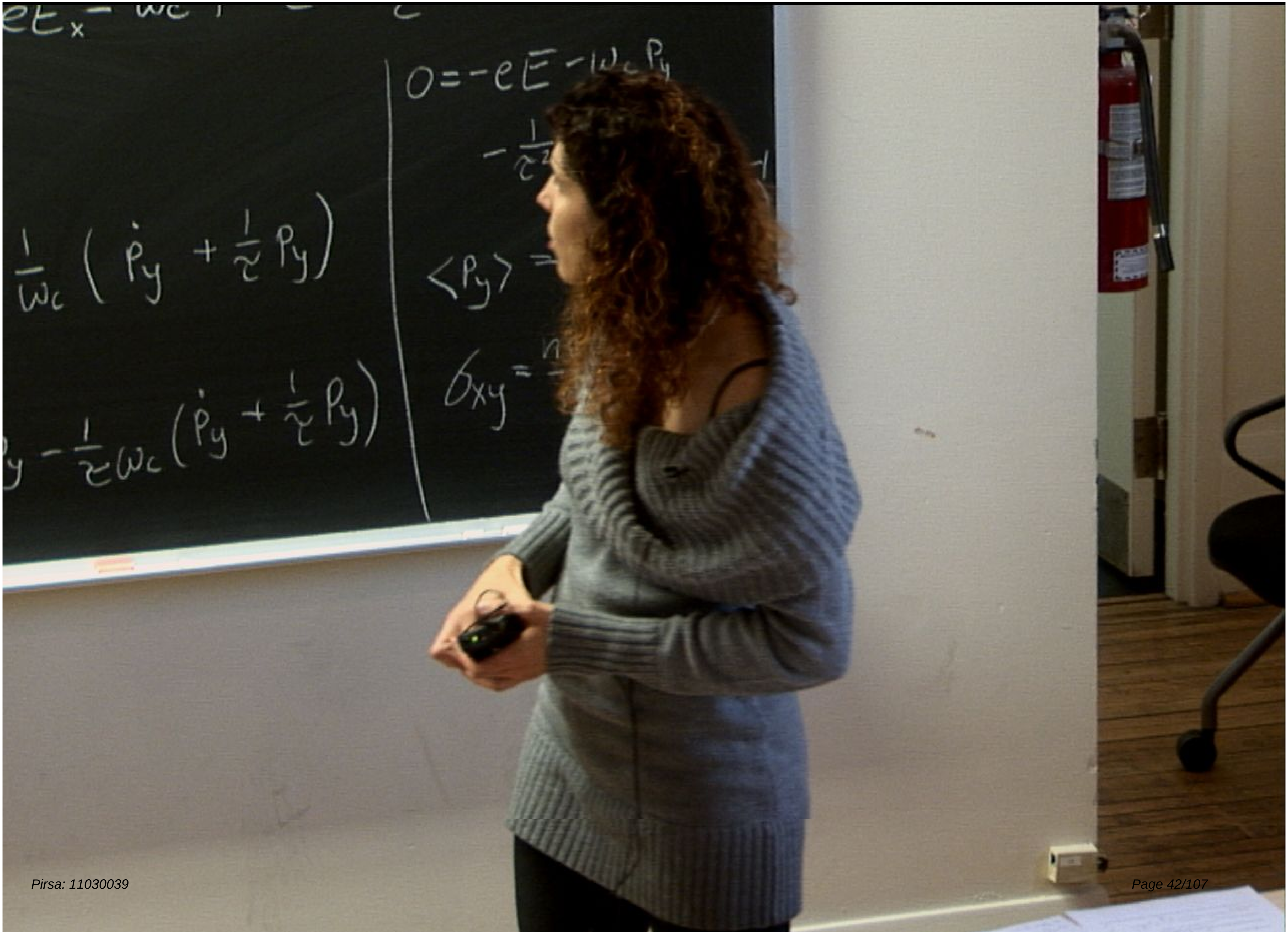
$\dot{P} = -$ ...

1) $\dot{P}_x =$ ...

2) $\ddot{P}_y =$ ...

2→1) $\frac{1}{\omega_c}$ ...


$m \frac{dV}{dt} = -eE + f_0 - e\vec{V} \times \vec{B}$
$X(t) = l_B \cos(\omega_c t)$
$y(t) = l_B \sin(\omega_c t)$
$l_B = V_0 \cdot \frac{1}{\omega_c}$
L_y
I
L_x
V
$I_y = G V_x$
$L_x J_y = G E \cdot L_x$
$J_y = G E_x \to \sigma_{xy}$
l_B
$\hat{\sigma} = \frac{ne^2\tau}{m} \cdot \frac{1}{1+\omega_c^2\tau^2} \begin{pmatrix} 1 & \omega_c\tau \\ -\omega_c\tau & 1 \end{pmatrix}$
$\tau \gg \omega_c^{-1}$
$\tau\omega_c \gg 1$
$\sigma_{xy} = \frac{ne^2\tau}{m} \frac{1}{\omega_c \tau} = \frac{ne^2}{m} \cdot \frac{m}{eB} = \frac{ne}{B}$
$\dot{p} =$
$\sigma =$
$\dot{P} = -$
1) $\dot{P}_x =$
2) $\dot{P}_y =$
$2 \to 1)$ $\frac{1}{\omega_c}$



$V_{gr} \times B$

$\downarrow$

$\frac{\partial E}{\partial k}$

$0 = -eE$

$-\frac{1}{\tau^2 \omega}$

$\langle P_y \rangle =$

$\sigma_{xy} = \frac{n}{}$

$\frac{1}{\omega_c}\left(\ddot{P}_y + \frac{1}{\tau}\dot{P}_y\right) = -eE - \omega_c P_y - \frac{1}{\tau \omega_c}\left(\dot{P}_y + \frac{1}{\tau} P_y\right)$

$$V_{gr} \times B$$

$$\downarrow$$

$$\frac{1}{\hbar}\frac{\partial E}{\partial k} \times \hat{z}$$

$$0 = -eE \ldots$$

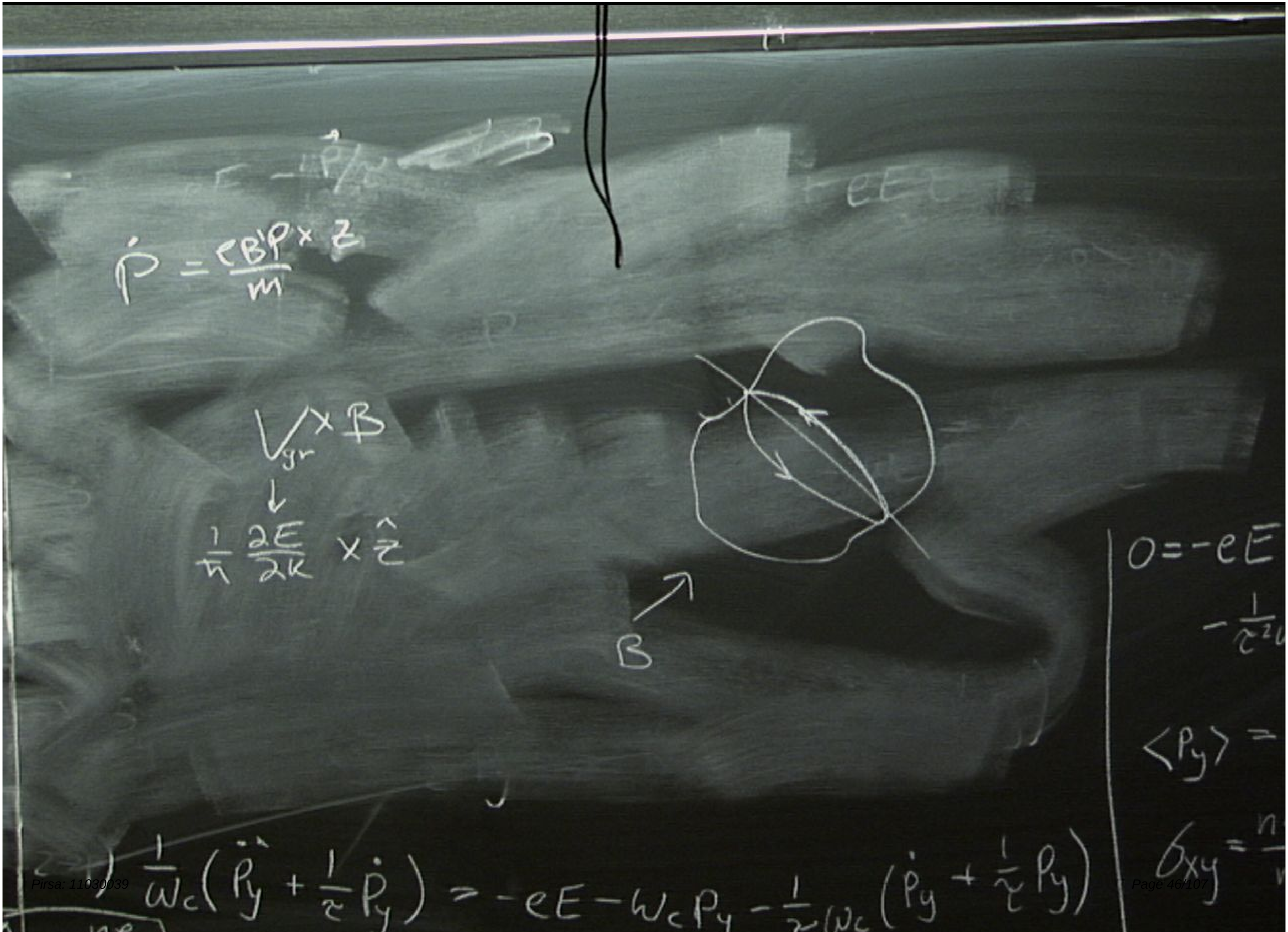
$$-\frac{1}{\tau^2 \ldots}$$

$$\langle P_y \rangle = \ldots$$

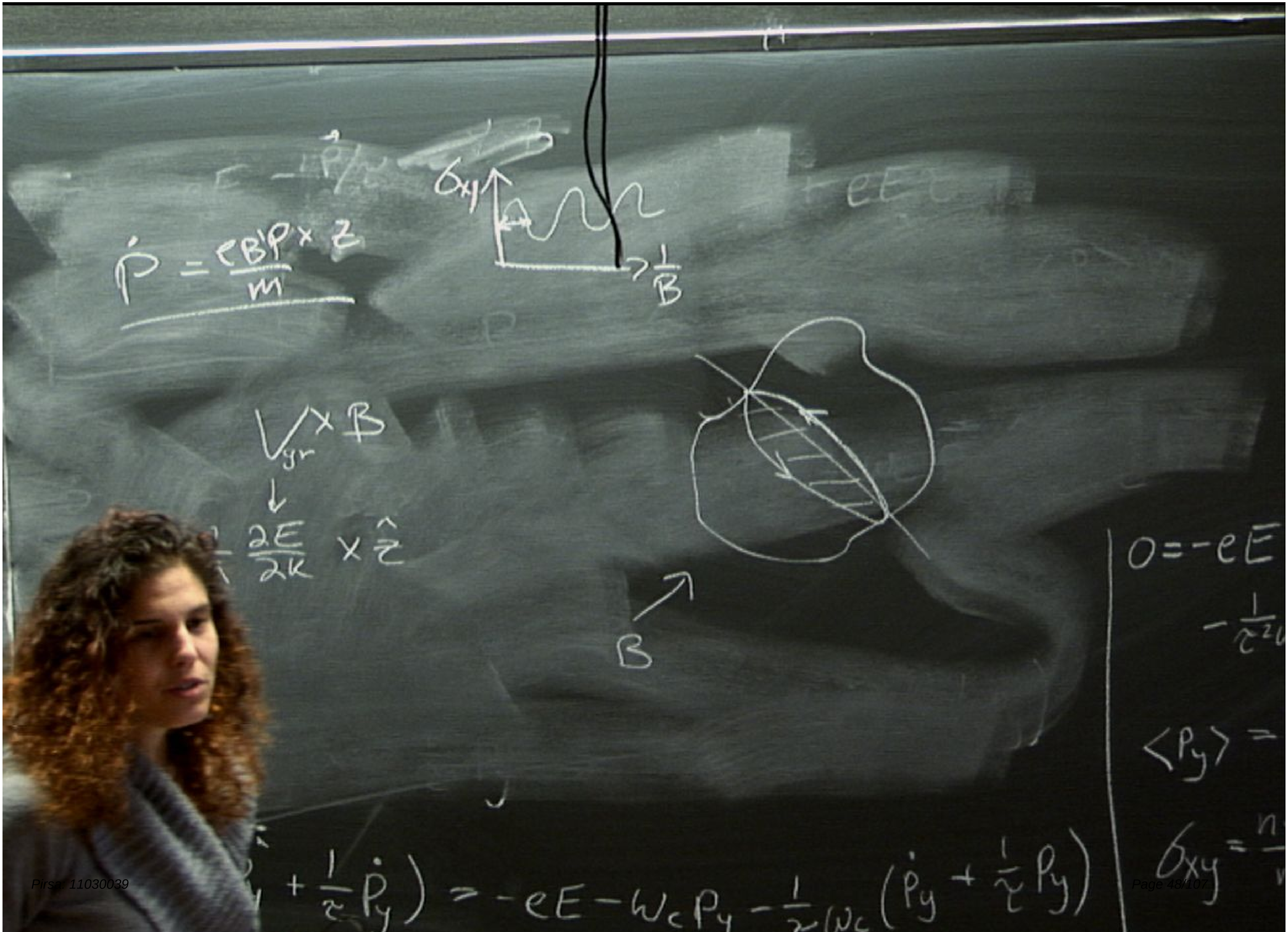
$$\sigma_{xy} = \ldots$$

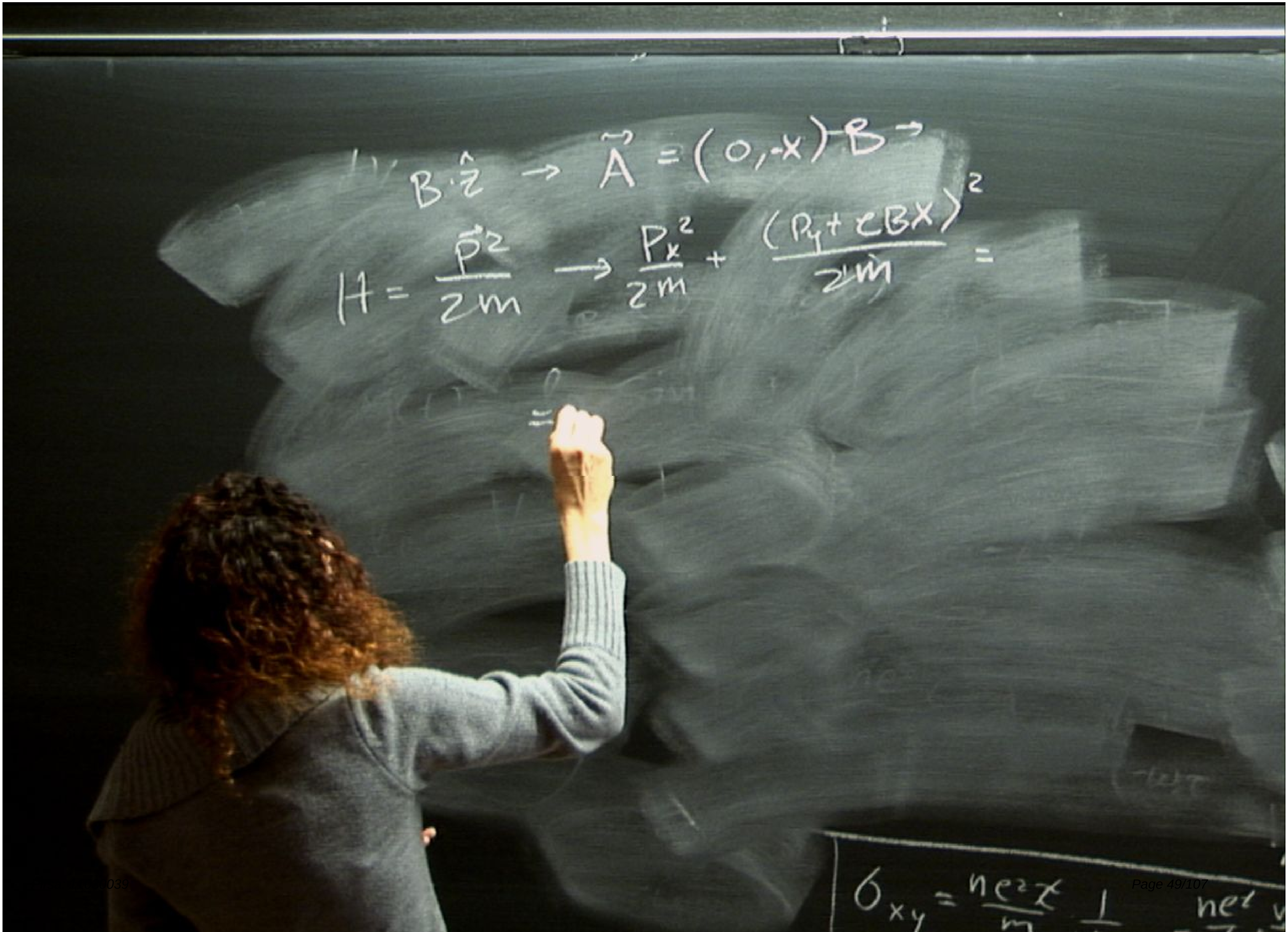
$$\frac{1}{\omega_c}\left(\ddot{P}_y + \frac{1}{\tau}\dot{P}_y\right) = -eE - \omega_c P_y - \frac{1}{\tau \omega_c}\left(\dot{P}_y + \frac{1}{\tau} P_y\right)$$

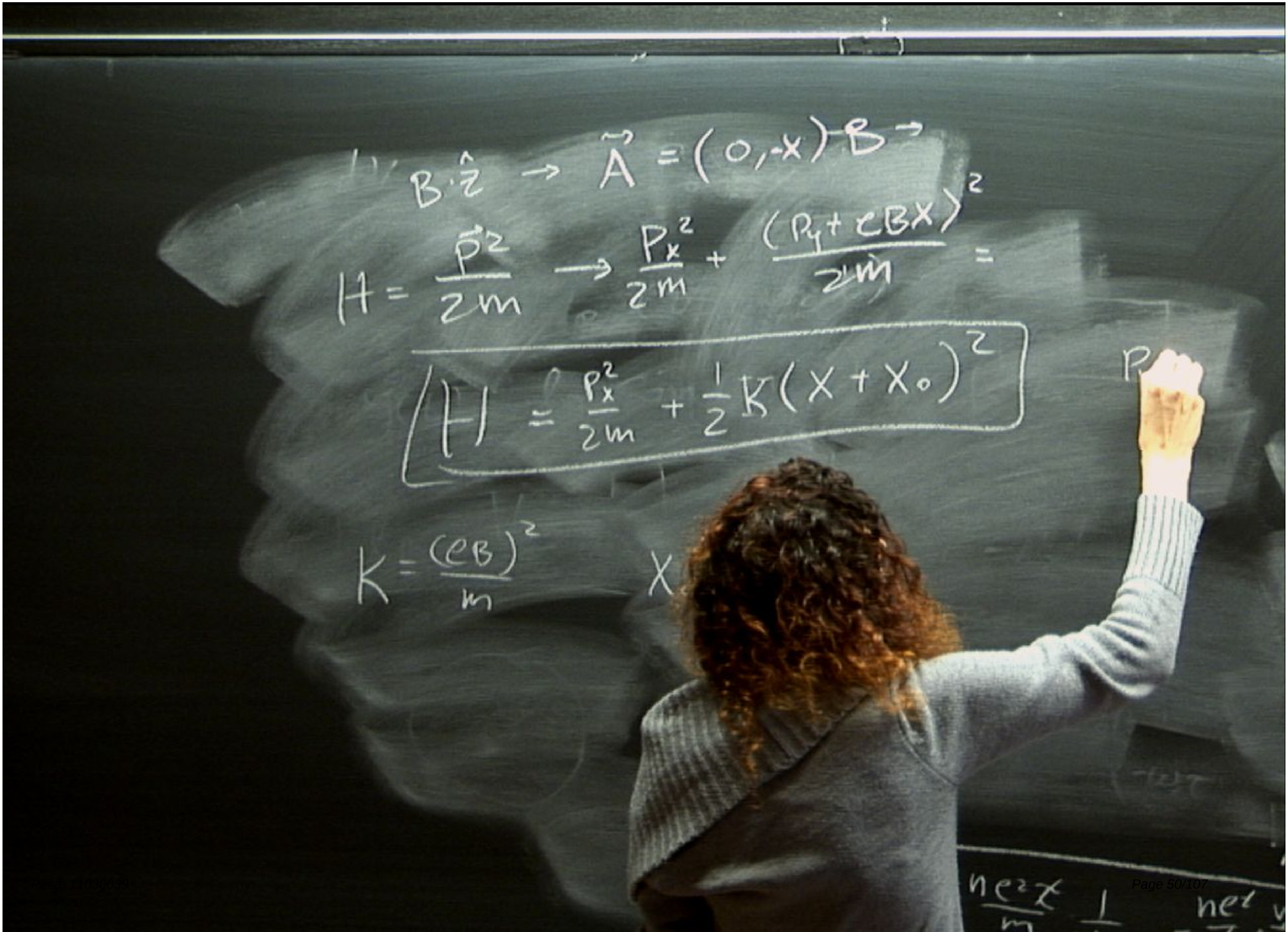
V_gr × B
1/ħ ∂E/∂k × ẑ
B
0 = −eE
⟨P_y⟩ =
σ_xy =
E − ω_c P_y − 1/τ ω_c (Ṗ_y + 1/τ P_y)

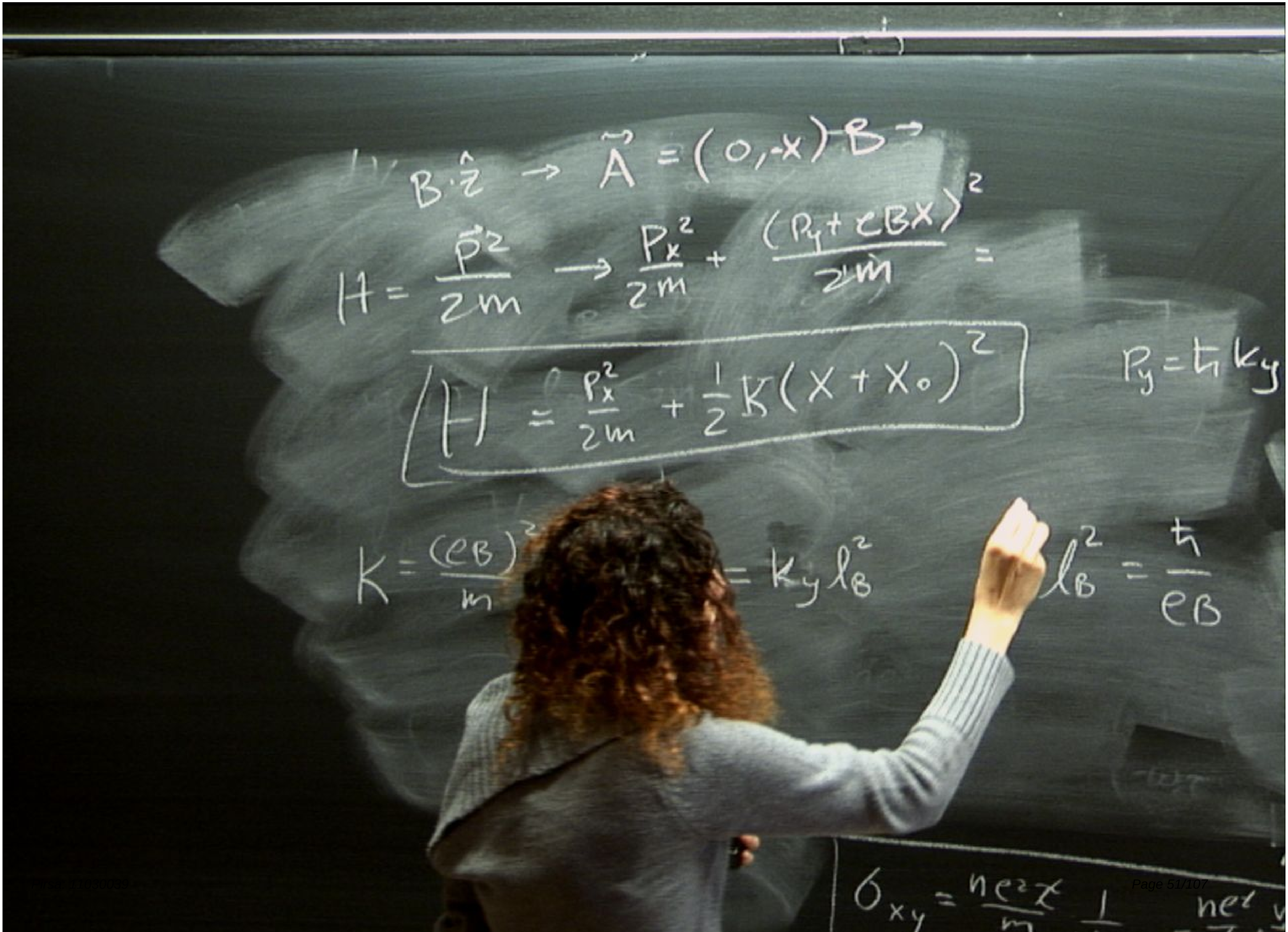

ṗ = eB p × z / m
V_gr × B
1/ħ ∂E/∂k × ẑ
B
0 = −eE
⟨P_y⟩ =
σ_xy =
1/ω_c (P̈_y + 1/τ Ṗ_y) = −eE − ω_c P_y − 1/τ ω_c (Ṗ_y + 1/τ P_y)

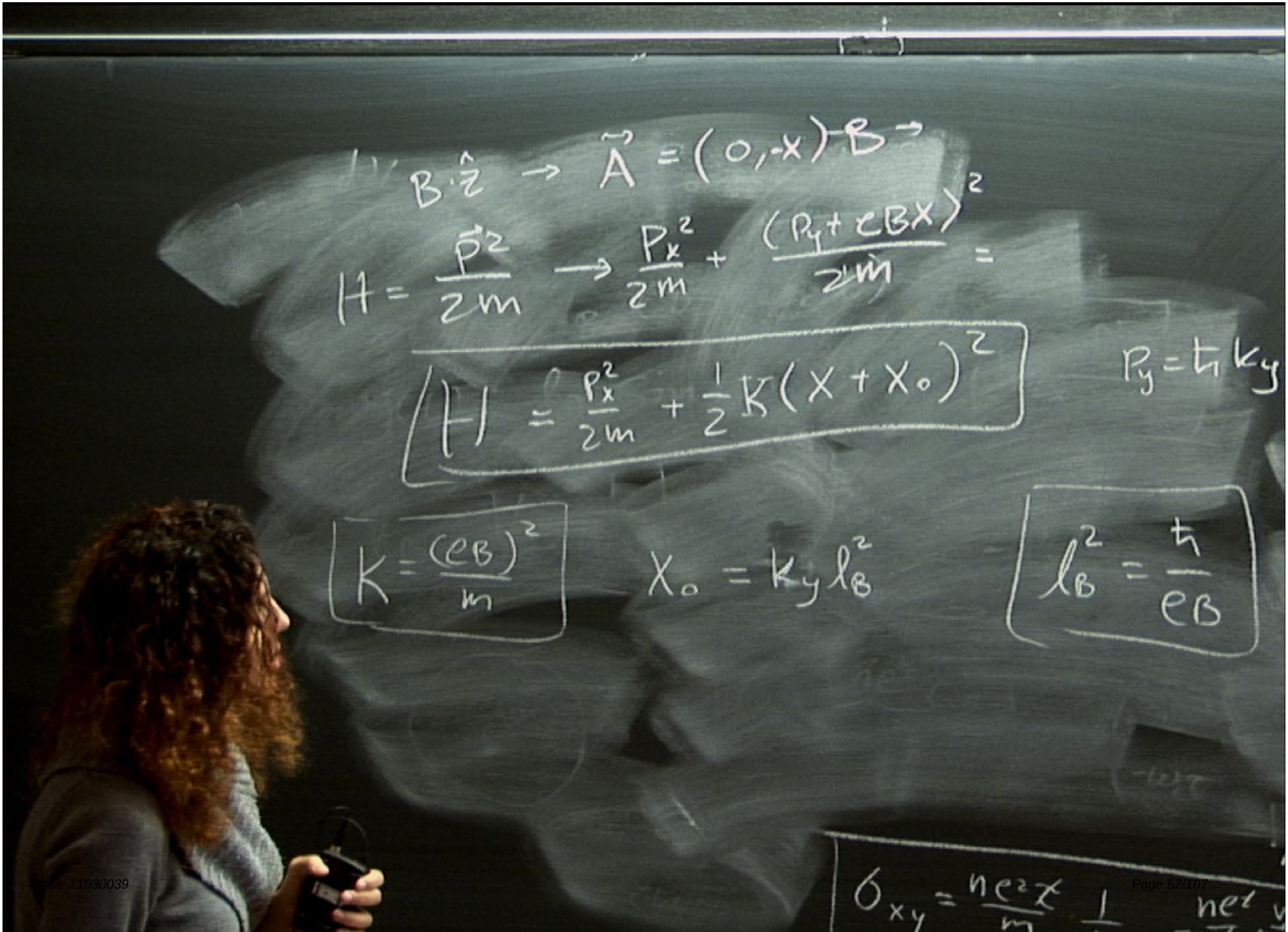
ṗ = eB'p × z / m
V_gr × B
1/ħ ∂E/∂k ×
B
O = −eE
⟨P_y⟩ =


V_gr × B
B
O = -eE
⟨P_y⟩ =
σ_xy =

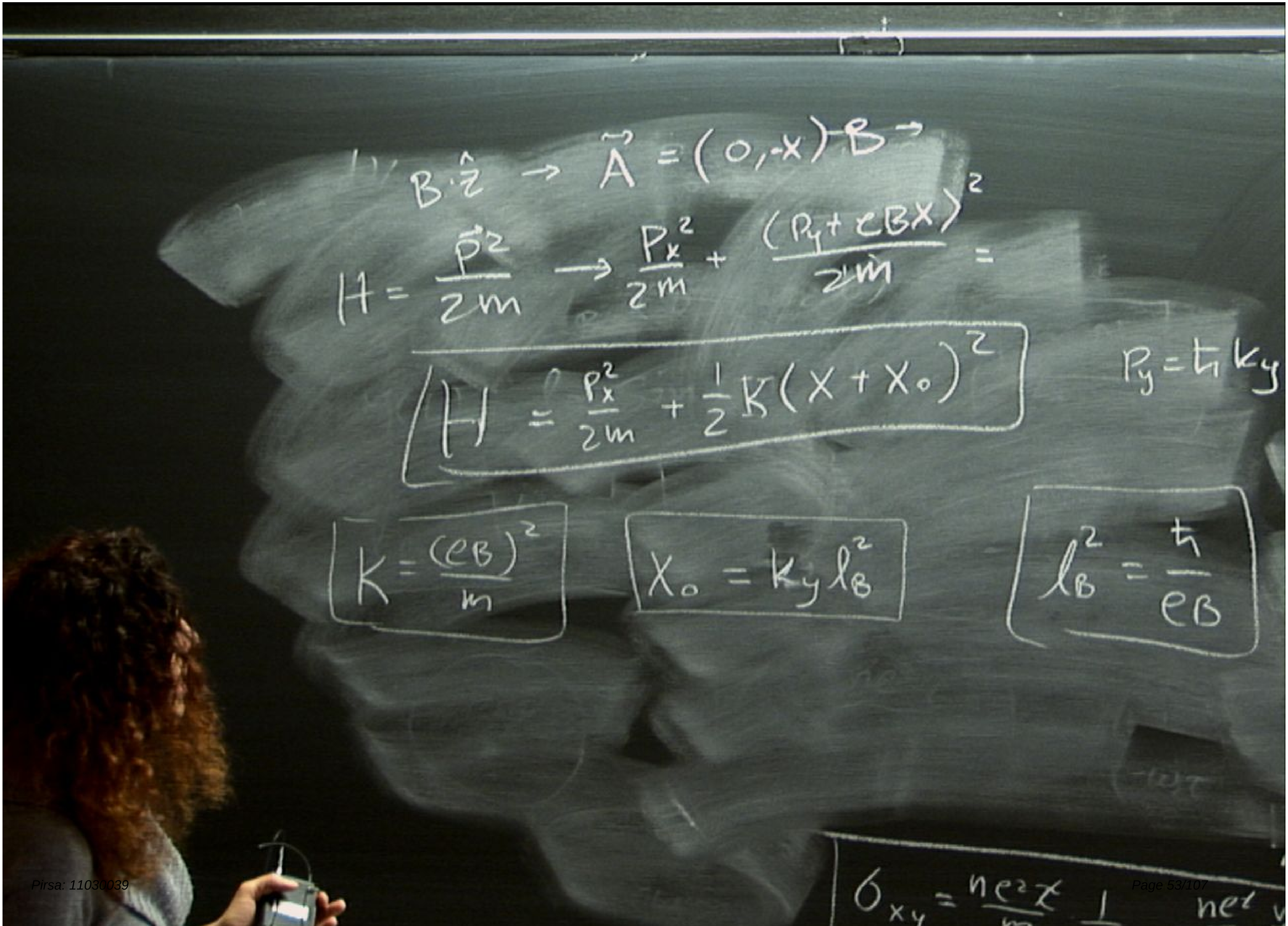

B·ẑ → A = (0, -x) B →
H = p²/2m → Px²/2m + (Py + eBx)²/2m =
σxy = ne²τ/m

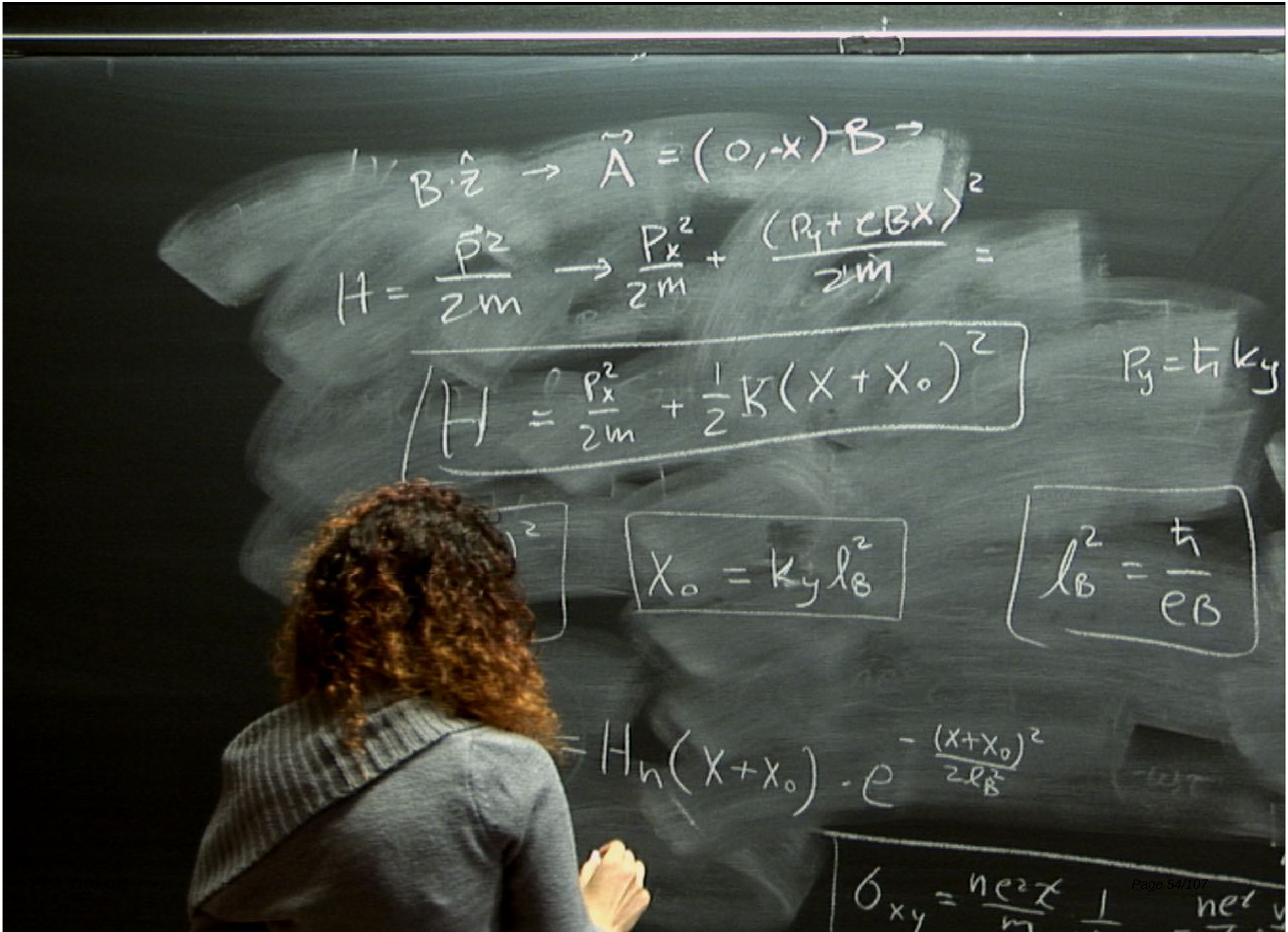

B·ẑ → A⃗ = (0, x) B
H = p⃗²/2m → Px²/2m + (Py + eBX)²/2m =
H = Px²/2m + ½K(X + X₀)²
K = (eB)²/m
X

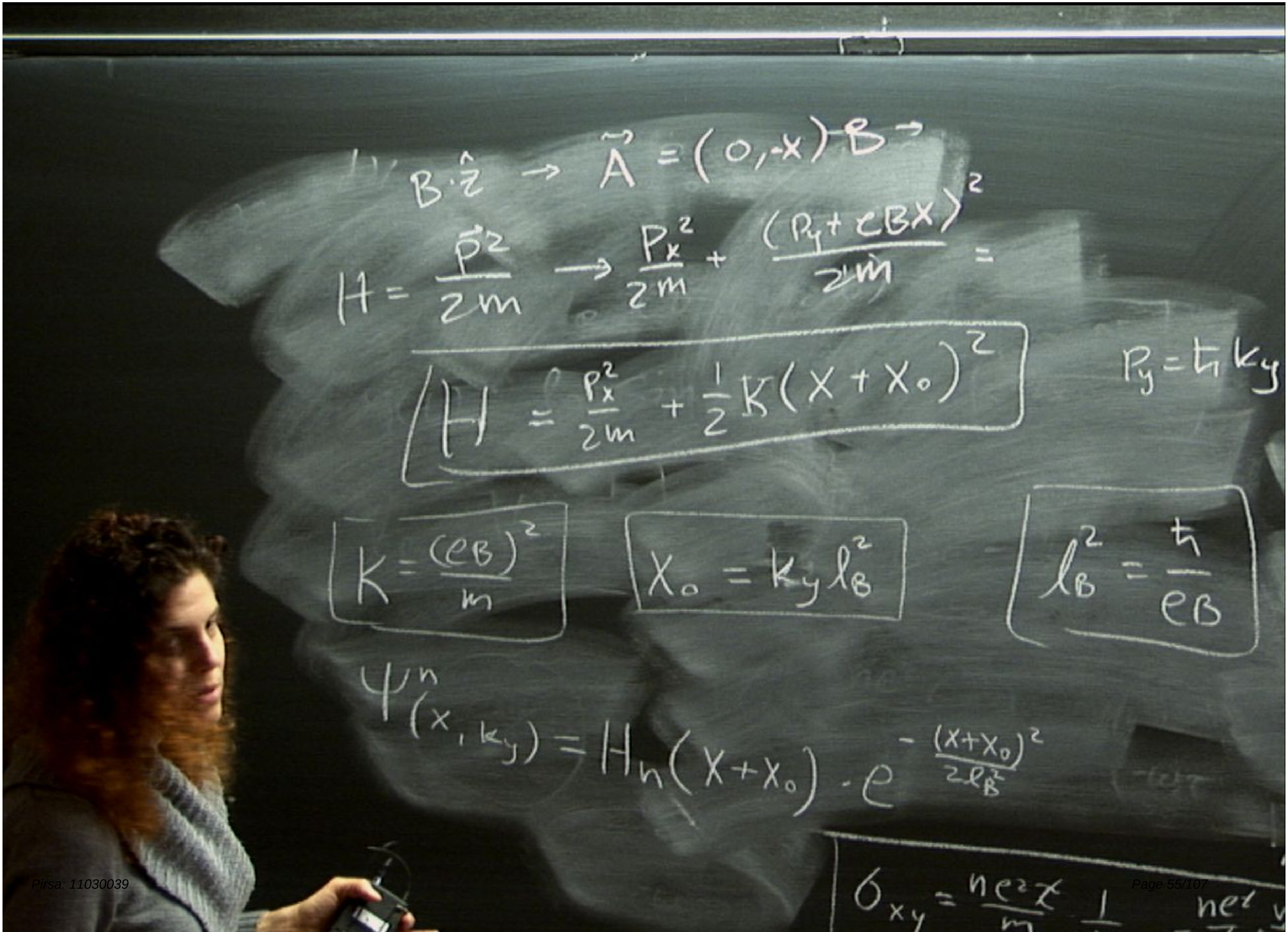

B·ẑ → A⃗ = (0, x) B →
H = p⃗²/2m → Px²/2m + (Py + eBx)²/2m =
Py = ħ ky
H = Px²/2m + ½ K (X + X₀)²
K = (eB)²/m
= ky lB²
lB² = ħ/eB
σxy = ne²τ/m



B·ẑ → A = (0,-x) B
H = p²/2m → Px²/2m + (Py + eBX)²/2m =
H = Px²/2m + ½K(X + X₀)²
Py = ħky
K = (eB)²/m
X₀ = ky lB²
lB² = ħ/eB


B·ẑ → A⃗ = (0, x) B
H = p⃗²/2m → Px²/2m + (Py + eBX)²/2m =
H = Px²/2m + ½K(X + X₀)²
Py = ħ ky
K = (eB)²/m
X₀ = ky lB²
lB² = ħ/eB
σxy = ne²τ/m


B·ẑ → A⃗ = (0, x) B
H = p⃗²/2m → Px²/2m + (Py + eBx)²/2m =
H = Px²/2m + ½K(X + X₀)²
Py = ħky
X₀ = ky lB²
lB² = ħ/eB
Hn(X+X₀) · e^{-(X+X₀)²/2lB²}
σxy = ne²τ/m



B·ẑ → A⃗ = (0, x) B
H = p⃗²/2m → p_x²/2m + (p_y + eBx)²/2m =
H = p_x²/2m + ½K(x + x₀)²
p_y = ħk_y
K = (eB)²/m
x₀ = k_y l_B²
l_B² = ħ/eB
ψⁿ(x, k_y) = H_n(x + x₀) · e^(−(x+x₀)²/2l_B²)
σ_xy = ne²τ/m

$B\hat{z} \to \vec{A} = (0, -x)B \to$

$$H = \frac{\vec{p}^2}{2m} \to \frac{p_x^2}{2m} + \frac{(p_y + eBx)^2}{2m} =$$

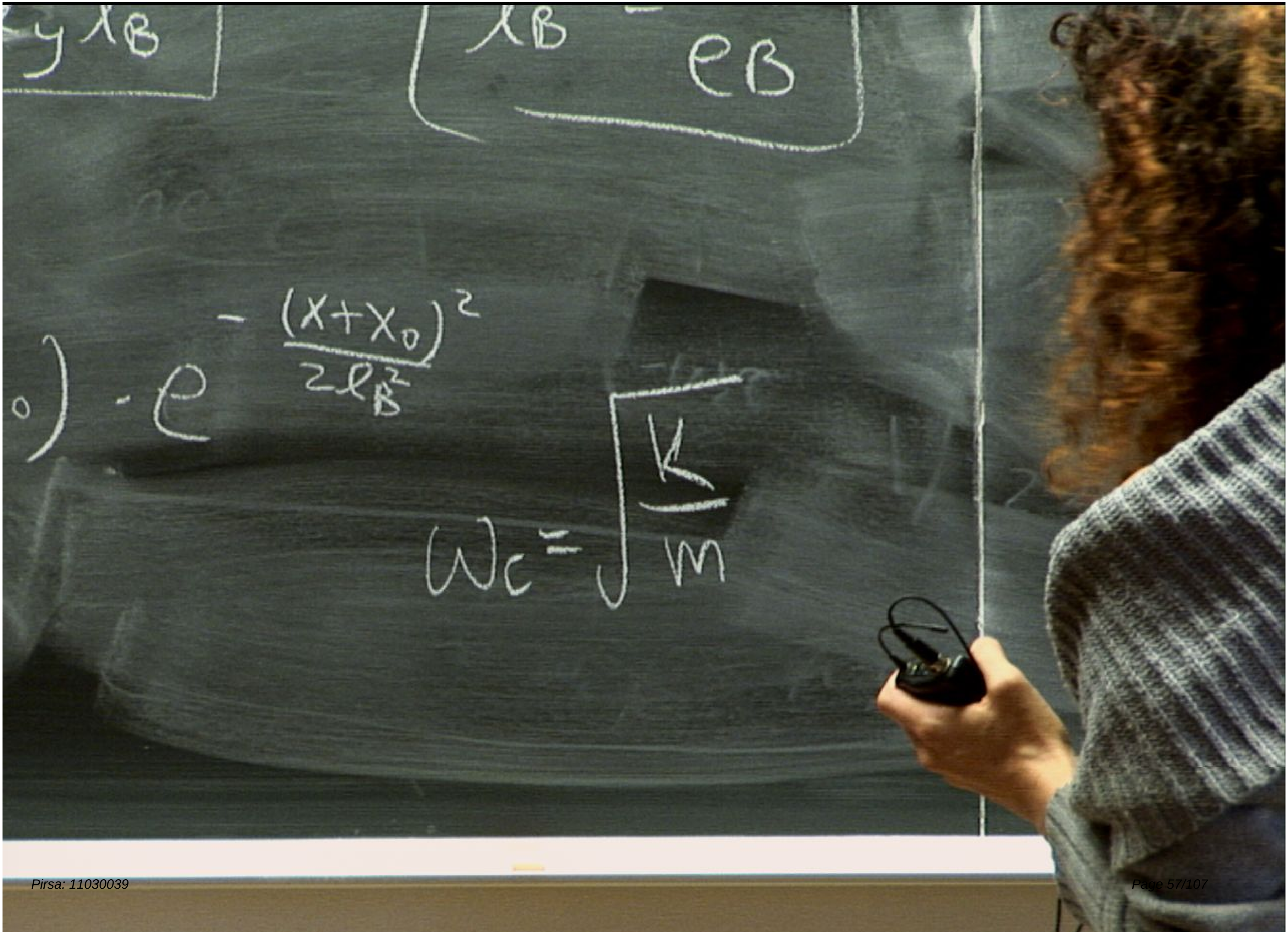
$$H = \frac{p_x^2}{2m} + \frac{1}{2}K(x + x_0)^2$$

$p_y = \hbar k_y$

$$K = \frac{(eB)^2}{m} \qquad x_0 = k_y \ell_B^2 \qquad \ell_B^2 = \frac{\hbar}{eB}$$

$$\psi^n_{(x, k_y)} = H_n(x + x_0) \cdot e^{-\frac{(x+x_0)^2}{2\ell_B^2}}$$

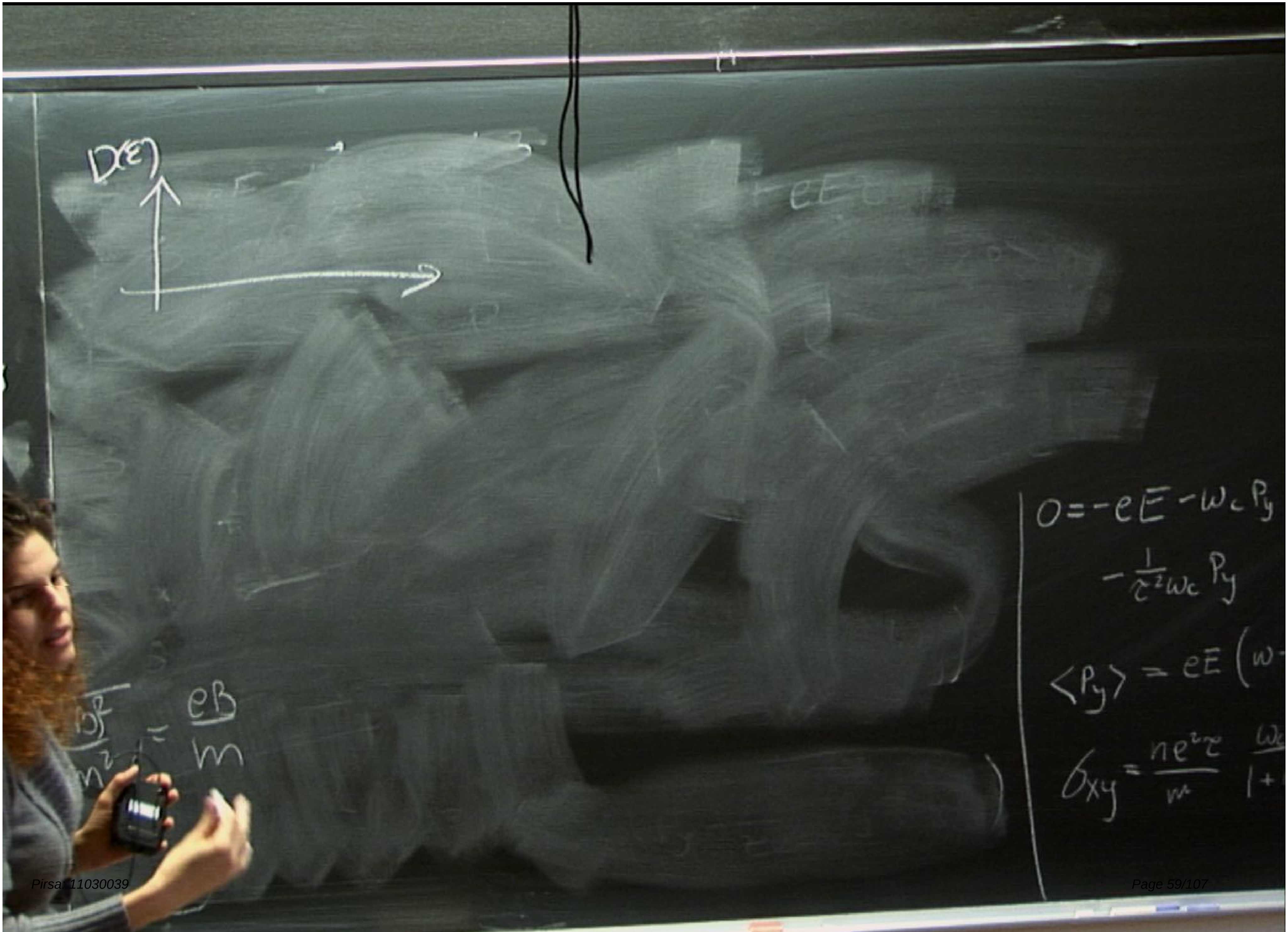
$$E_n = \hbar\omega_c\left(n + \frac{1}{2}\right)$$

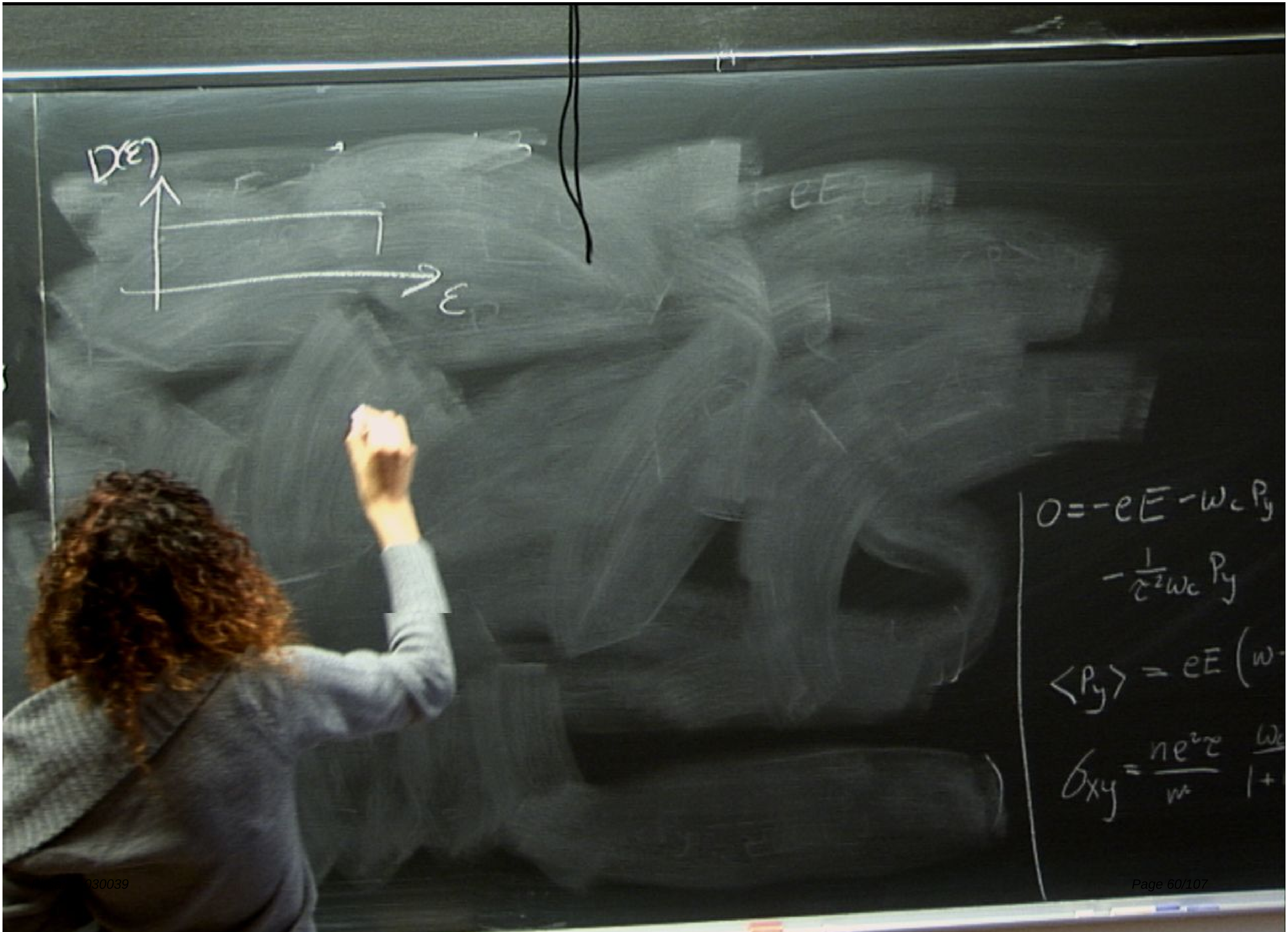

y λB
λB
eB
) · e^{- (x+x0)^2 / 2ℓB^2}
ωc = √(k/m)

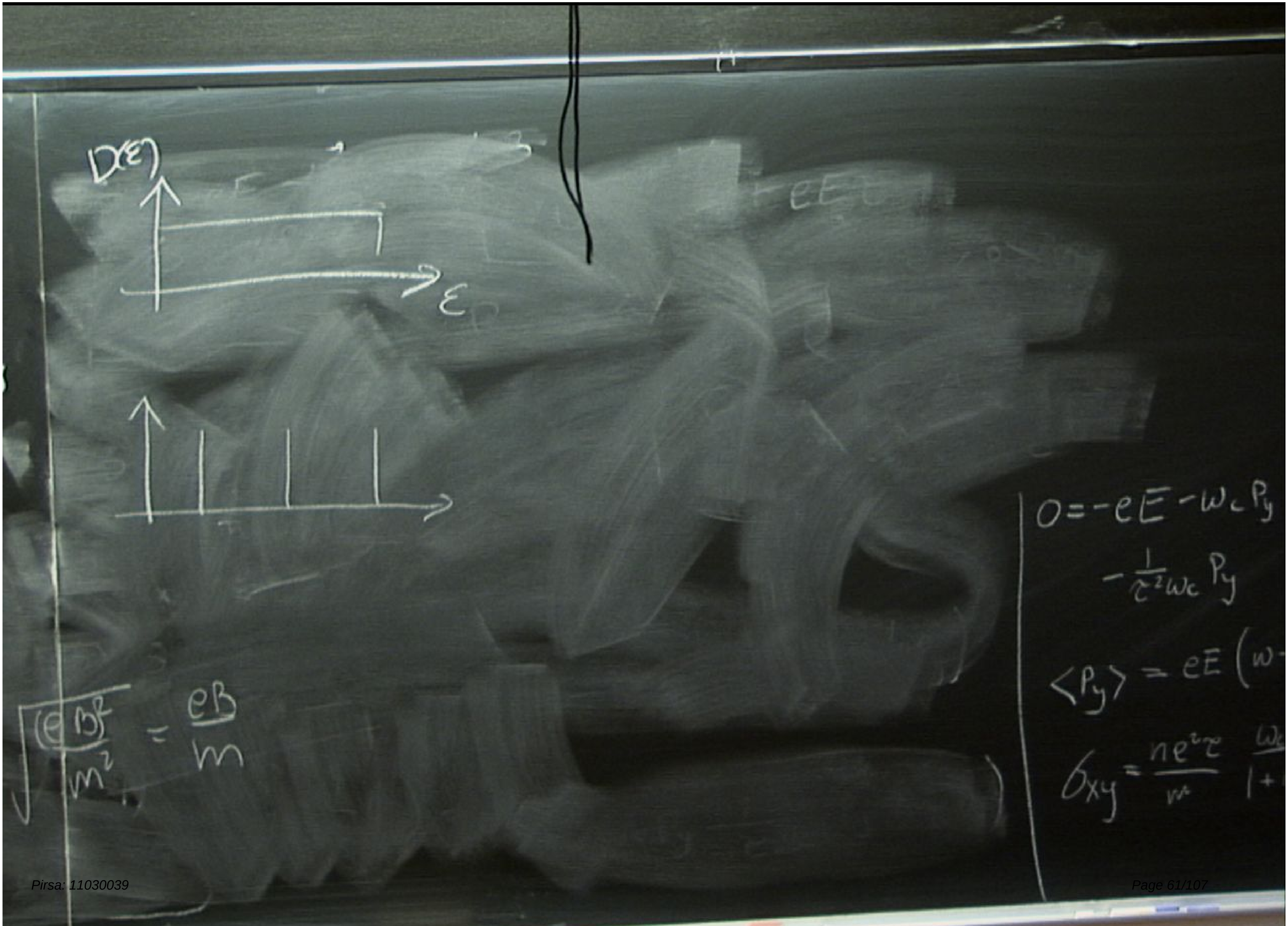
$$\ell_B \quad = \quad eB$$

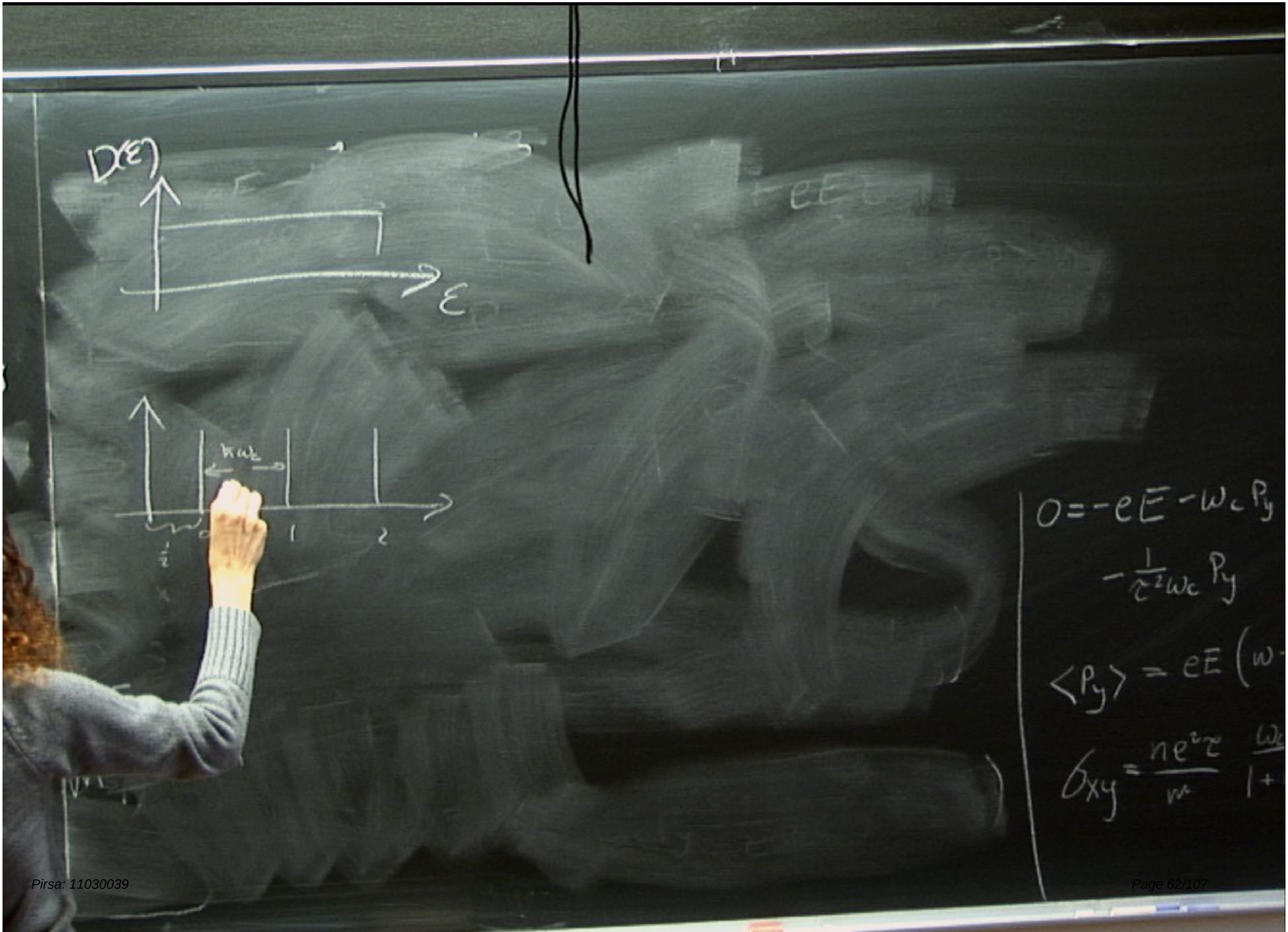
$$\frac{(x+x_0)^2}{2\ell_B^2}$$

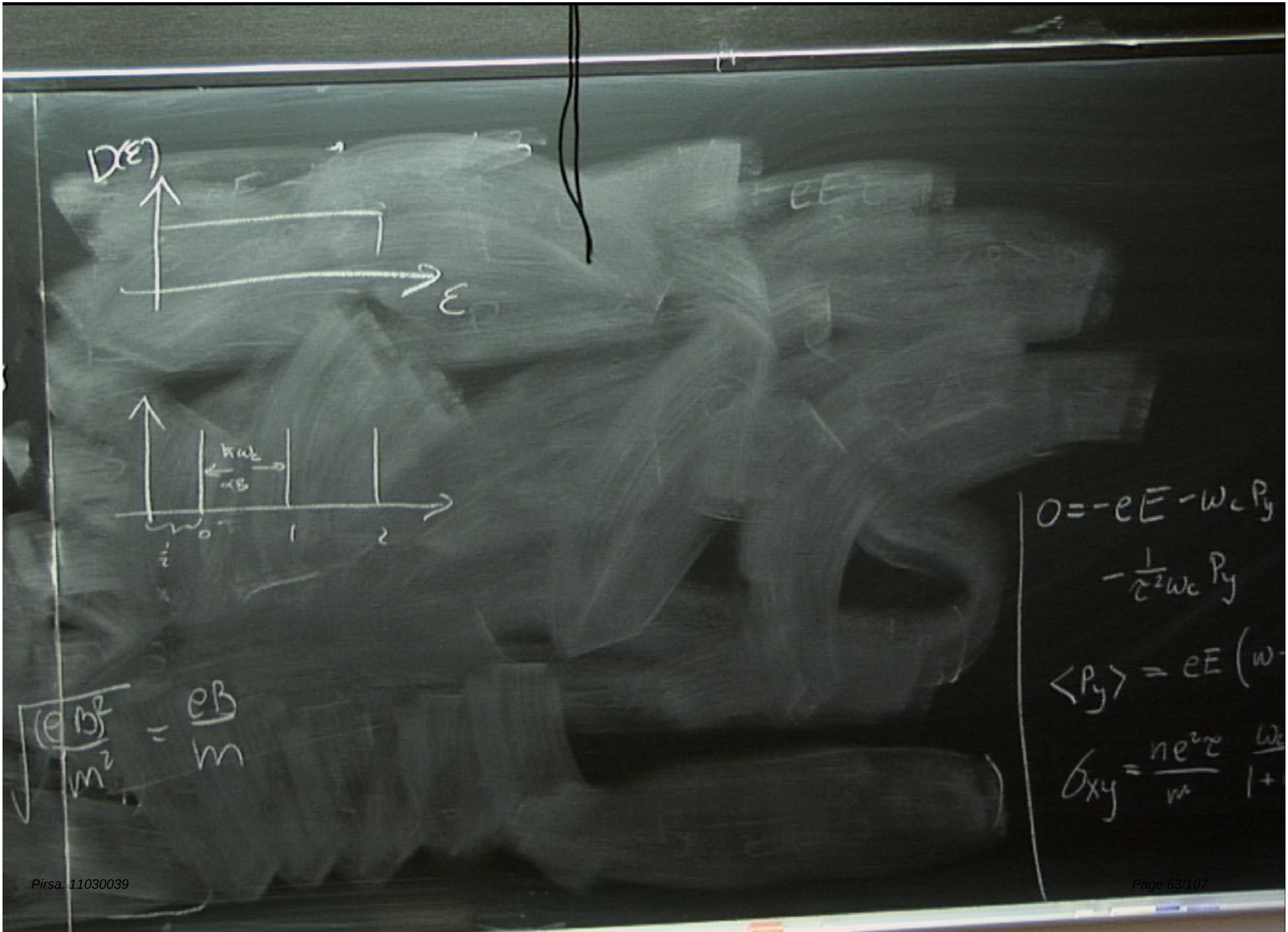
$$\omega_c = \sqrt{\frac{k}{m}} = \sqrt{\frac{(eB)^2}{m^2}} = \frac{eB}{m}$$


D(ε)
eB/m
O = -eE - ω_c P_y
- 1/(τ² ω_c) P_y
⟨P_y⟩ = eE (ω
σ_xy = ne²τ/m


D(ε)
ε_F
O = −eE − ω_c P_y
− 1/(τ² ω_c) P_y
⟨P_y⟩ = eE (ω
σ_xy = ne²τ/m


D(ε)
ε
0 = −eE − ω_c P_y
− 1/(τ² ω_c) P_y
⟨P_y⟩ = eE (ω
σ_xy = ne²τ/m
√((eB)²/m²) = eB/m


D(ε)
ε
ħω_c
1
2
0 = -eE - ω_c P_y
- 1/(τ²ω_c) P_y
⟨P_y⟩ = eE (ω
σ_xy = ne²τ/m


D(ε)
ε
ħω_c
∝B
0
1
2
1/2
√((eB)²/m²) = eB/m
0 = −eE − ω_c P_y
− 1/(τ²ω_c) P_y
⟨P_y⟩ = eE (ω
σ_xy = ne²τ/m

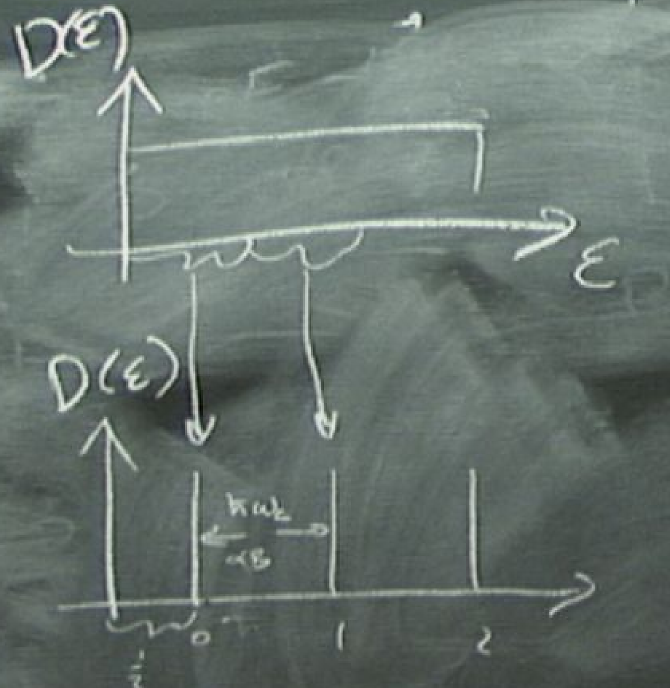
$$D(\varepsilon) = \sum_k \delta(\varepsilon - \varepsilon_k)$$

$$\sqrt{\frac{(eB)^2}{m^2}} = \frac{eB}{m}$$

$$0 = -eE - \omega_c P_y - \frac{1}{\tau^2 \omega_c} P_y$$

$$\langle P_y \rangle = eE \left(\omega \right.$$

$$\sigma_{xy} = \frac{ne^2\tau}{m} \frac{\omega_c}{1+}$$



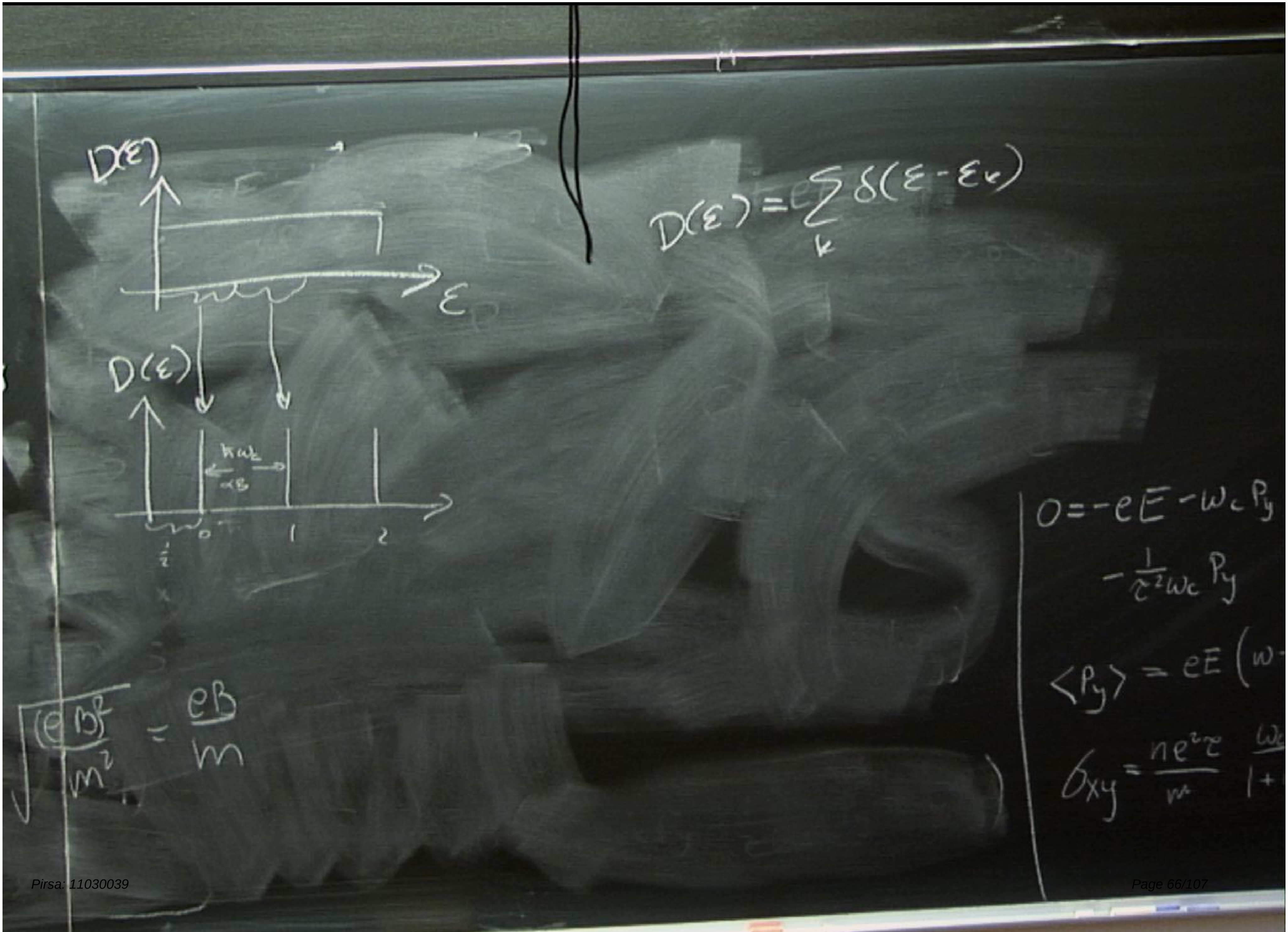
$$D(\varepsilon) = \sum_k \delta(\varepsilon - \varepsilon_k)$$

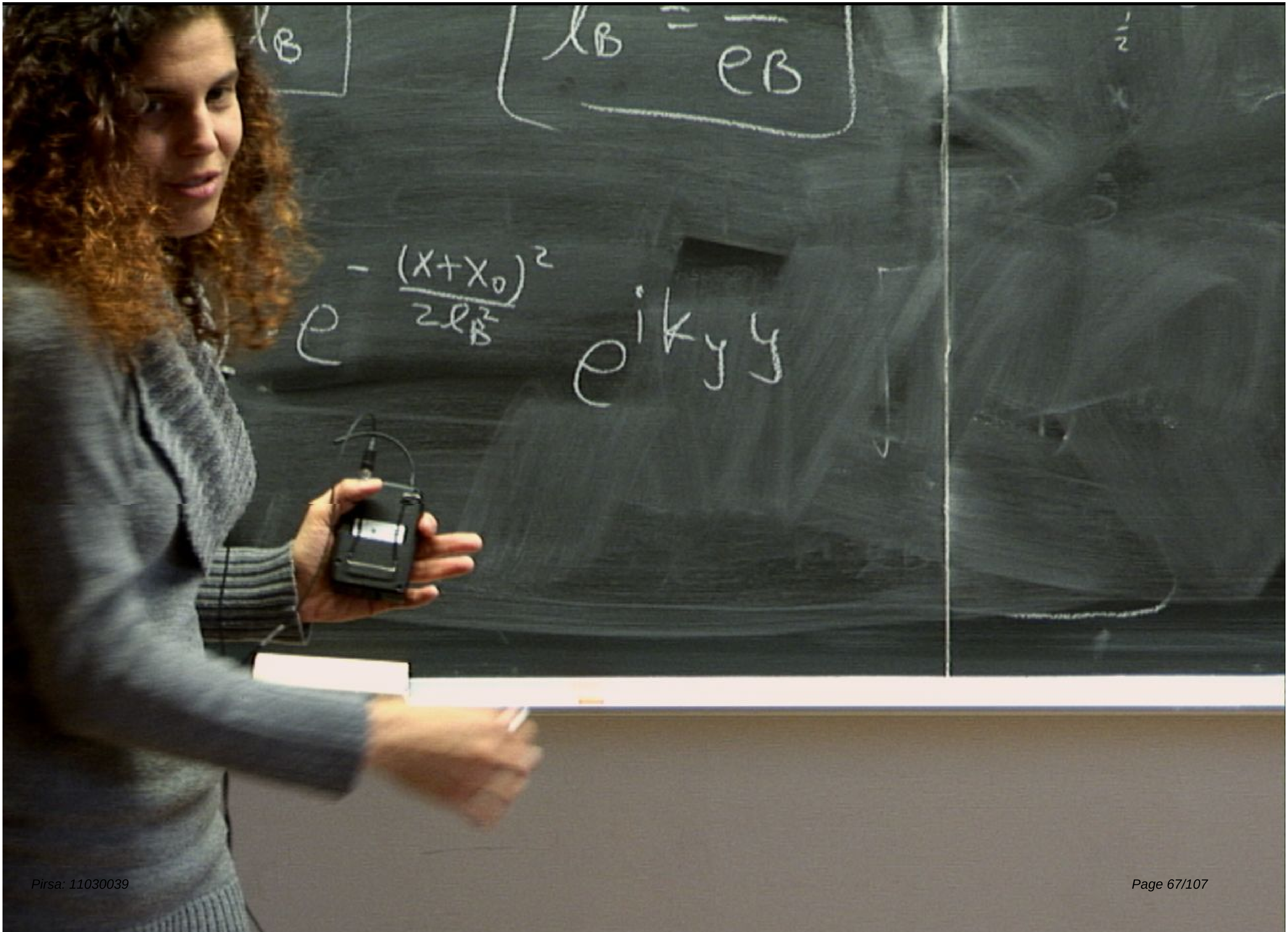
$$\sqrt{\frac{(eB)^2}{m^2}} = \frac{eB}{m}$$

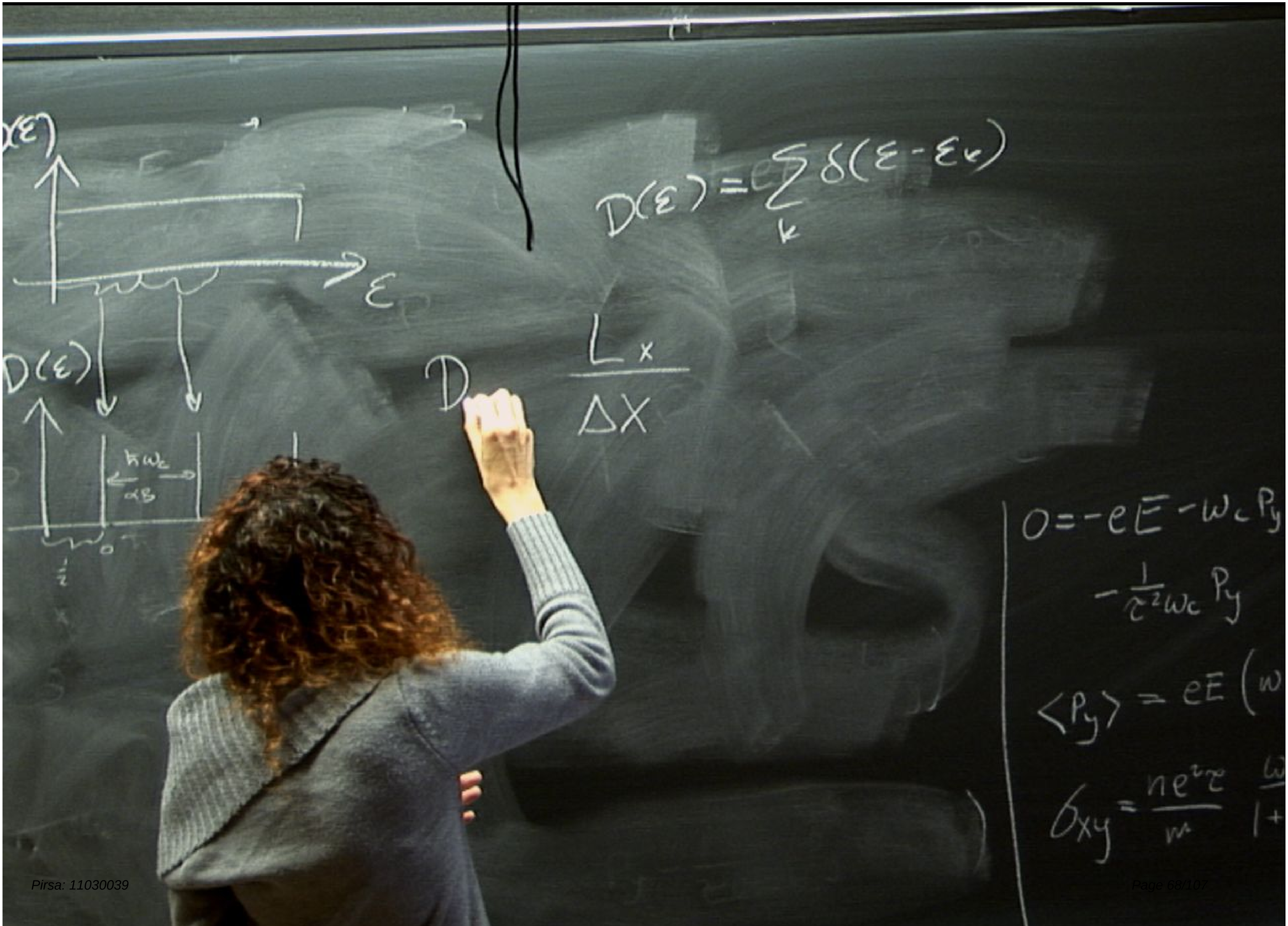
$$0 = -eE - \omega_c P_y - \frac{1}{\tau^2 \omega_c} P_y$$

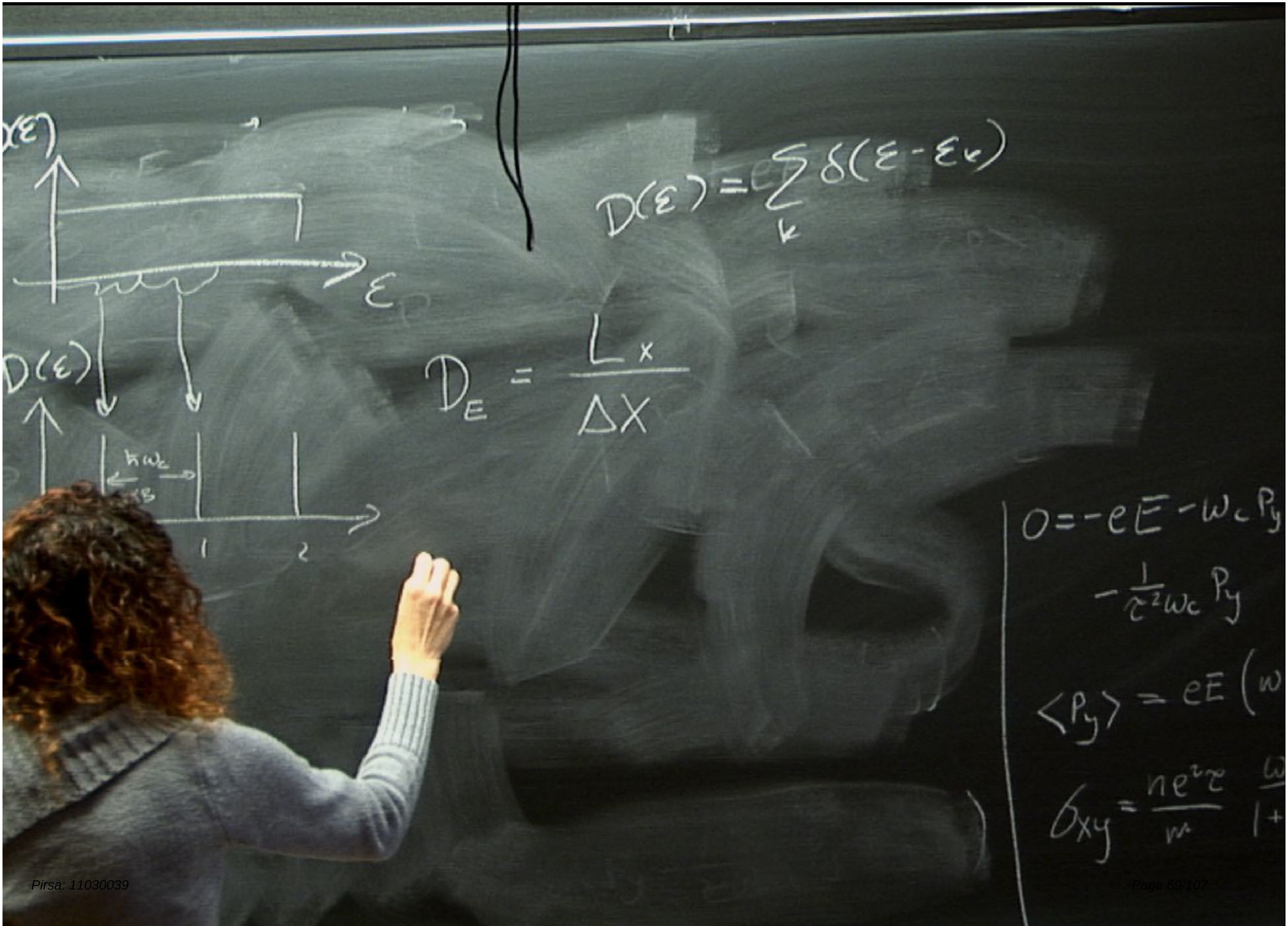
$$\langle P_y \rangle = eE \left(\omega \right. [illegible]$$

$$\sigma_{xy} = \frac{ne^2\tau}{m} \frac{\omega_c [illegible]}{1 + [illegible]}$$

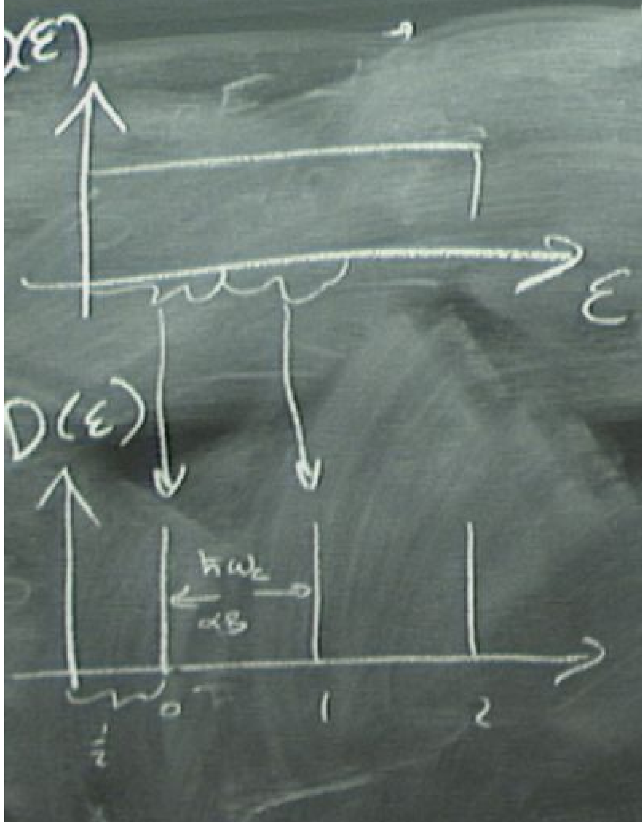

D(ε)
ε
D(ε)
ħω_c
eB
0
1
2
D(ε) = Σ_k δ(ε − ε_k)
√((eB)²/m²) = eB/m
0 = −eE − ω_c P_y
− 1/(τ² ω_c) P_y
⟨P_y⟩ = eE (ω
σ_xy = ne²τ/m


l_B
$l_B = \frac{}{eB}$
$e^{-\frac{(x+x_0)^2}{2l_B^2}}$
$e^{ik_y y}$


D(ε) = Σ_k δ(ε - ε_k)
ε
D(ε)
ħω_c
∝B
D
L_x
ΔX
0 = -eE - ω_c P_y
- 1/(τ²ω_c) P_y
<P_y> = eE
σ_xy = ne²τ/m


D(ε)
ε
D(ε)
ħω_c
1
2
D(ε) = Σ_k δ(ε - ε_k)
D_E = L_x / ΔX
0 = -eE - ω_c P_y
- 1/(τ²ω_c) P_y
<P_y> = eE (ω
σ_xy = ne²τ/m


D(ε) = Σ δ(ε - ε_k)
k
D(ε)
ε
ħω_c
∝B
0
1
2
D_E = L_x / ΔX
ΔK = l_B^2 (2π / L_y)
0 = -eE - ω_c P_y
- 1/(τ^2 ω_c) P_y
<P_y> = eE
σ_xy = ne^2τ / m



$$D(\varepsilon) = \sum_k \delta(\varepsilon - \varepsilon_k)$$

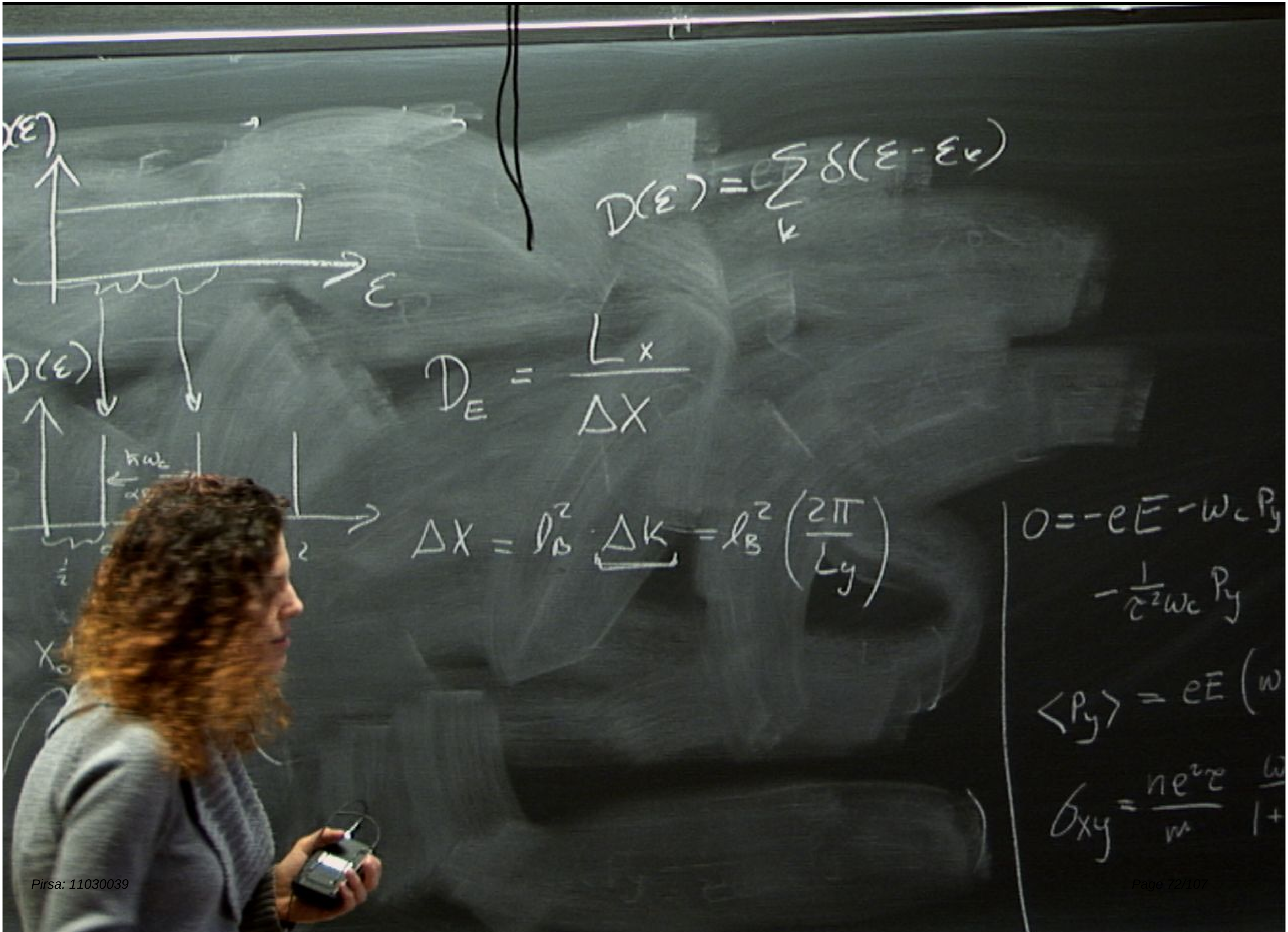
$$D_E = \frac{L_x}{\Delta X}$$

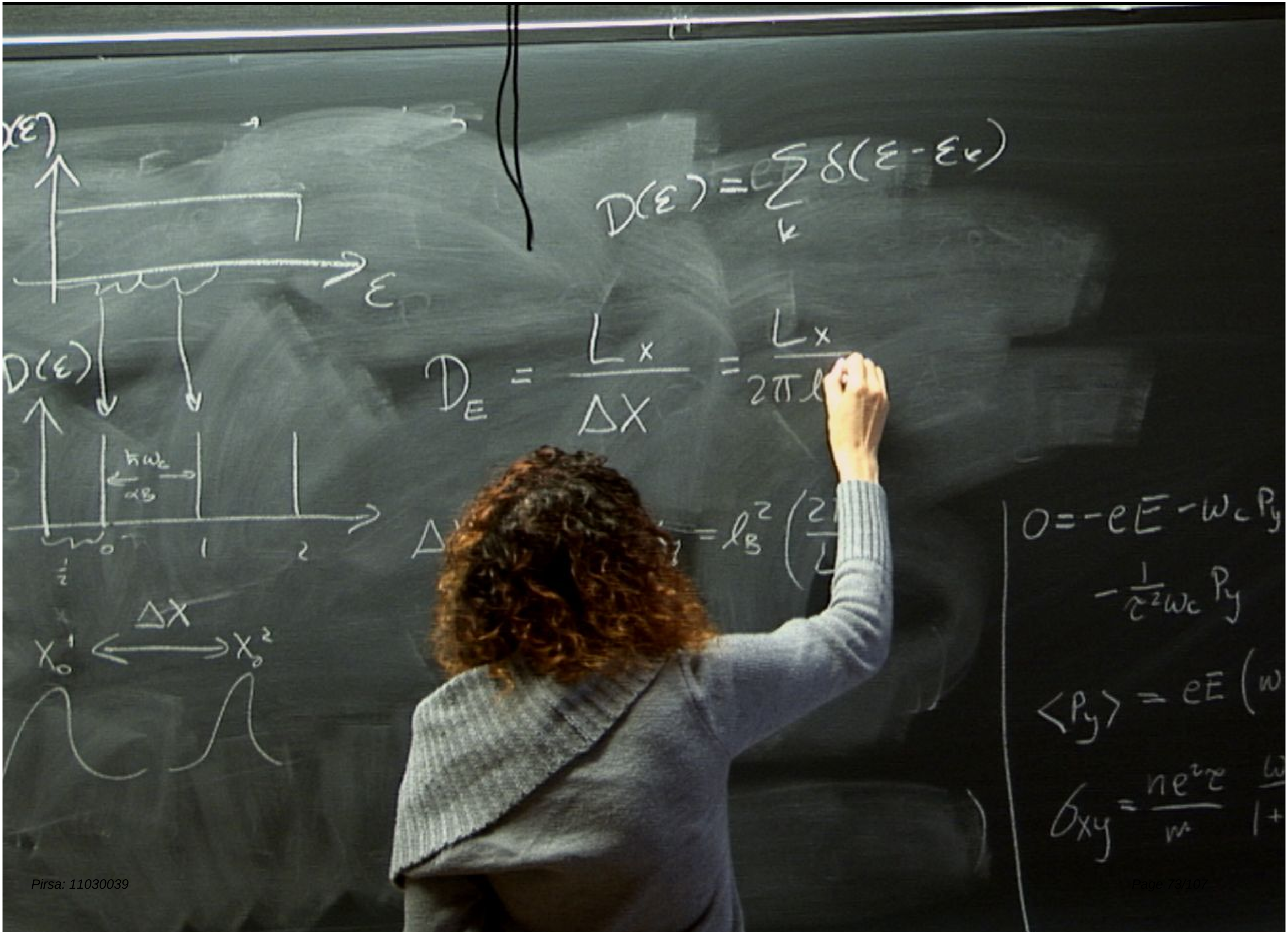
$$\Delta X = \ell_B^2 \cdot \Delta K = \ell_B^2 \left(\frac{2\pi}{L_y}\right)$$

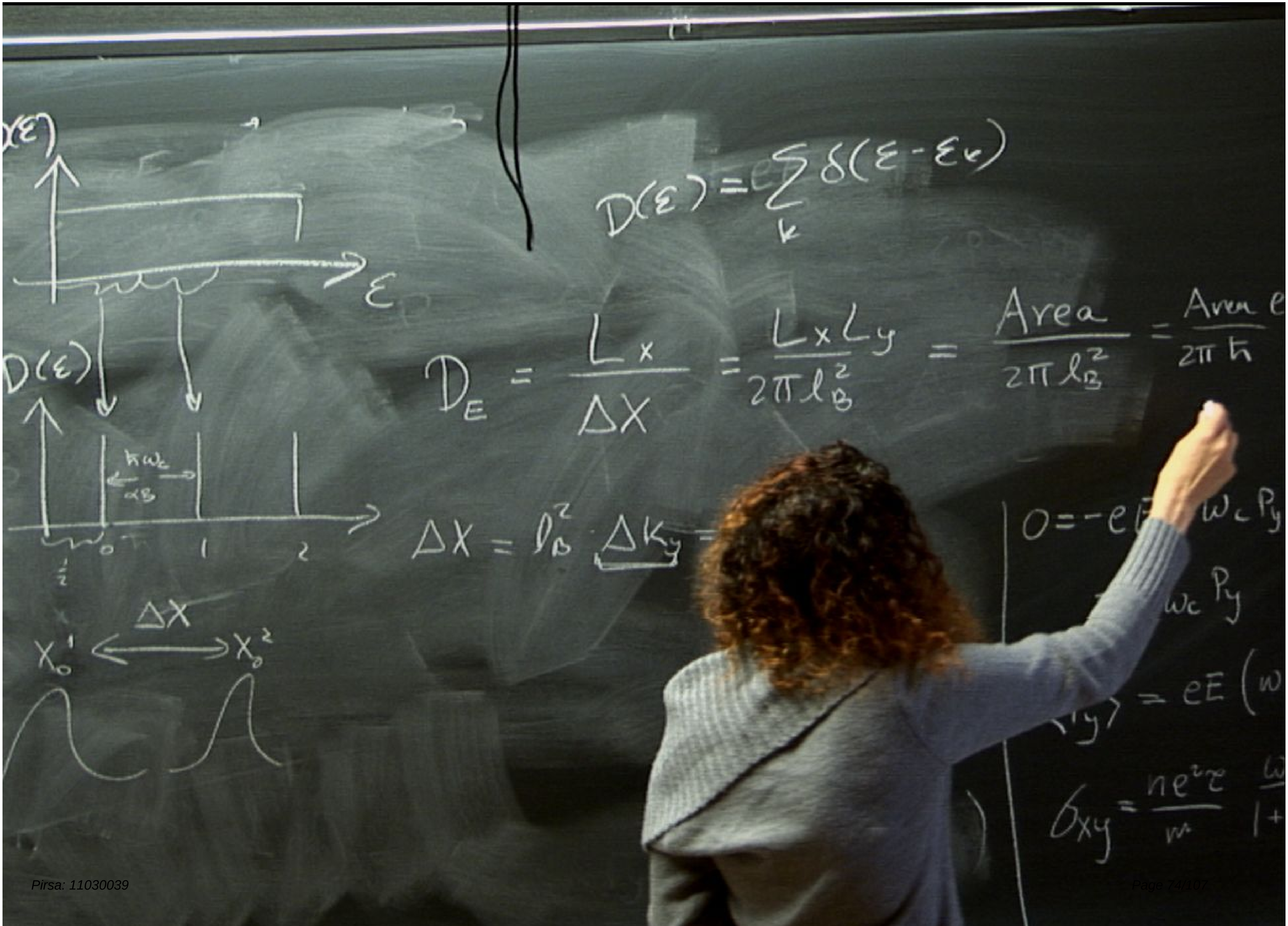
$$0 = -eE - \omega_c P_y - \frac{1}{\tau^2 \omega_c} P_y$$

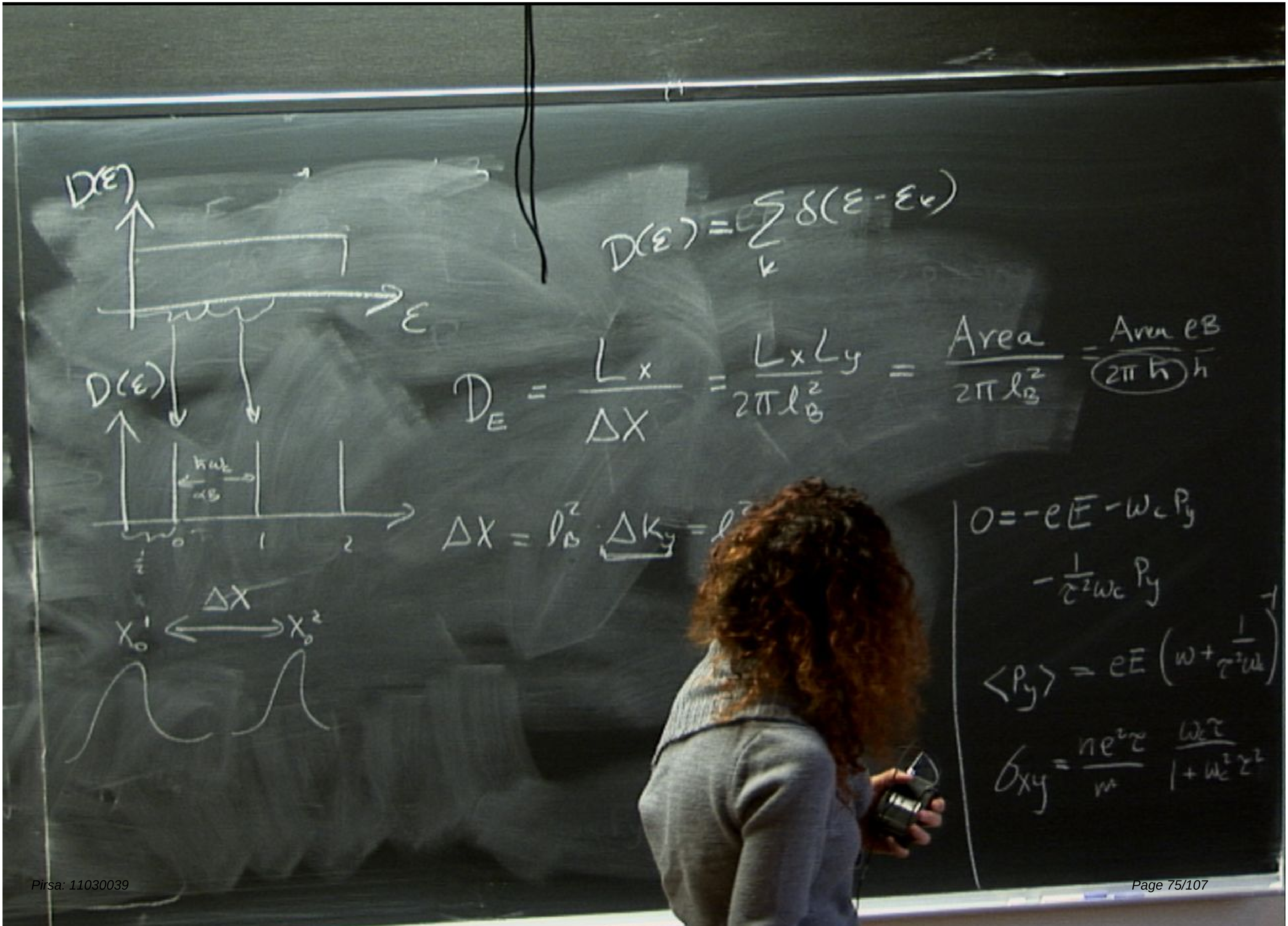
$$\langle P_y \rangle = eE \left(\omega \ldots\right.$$

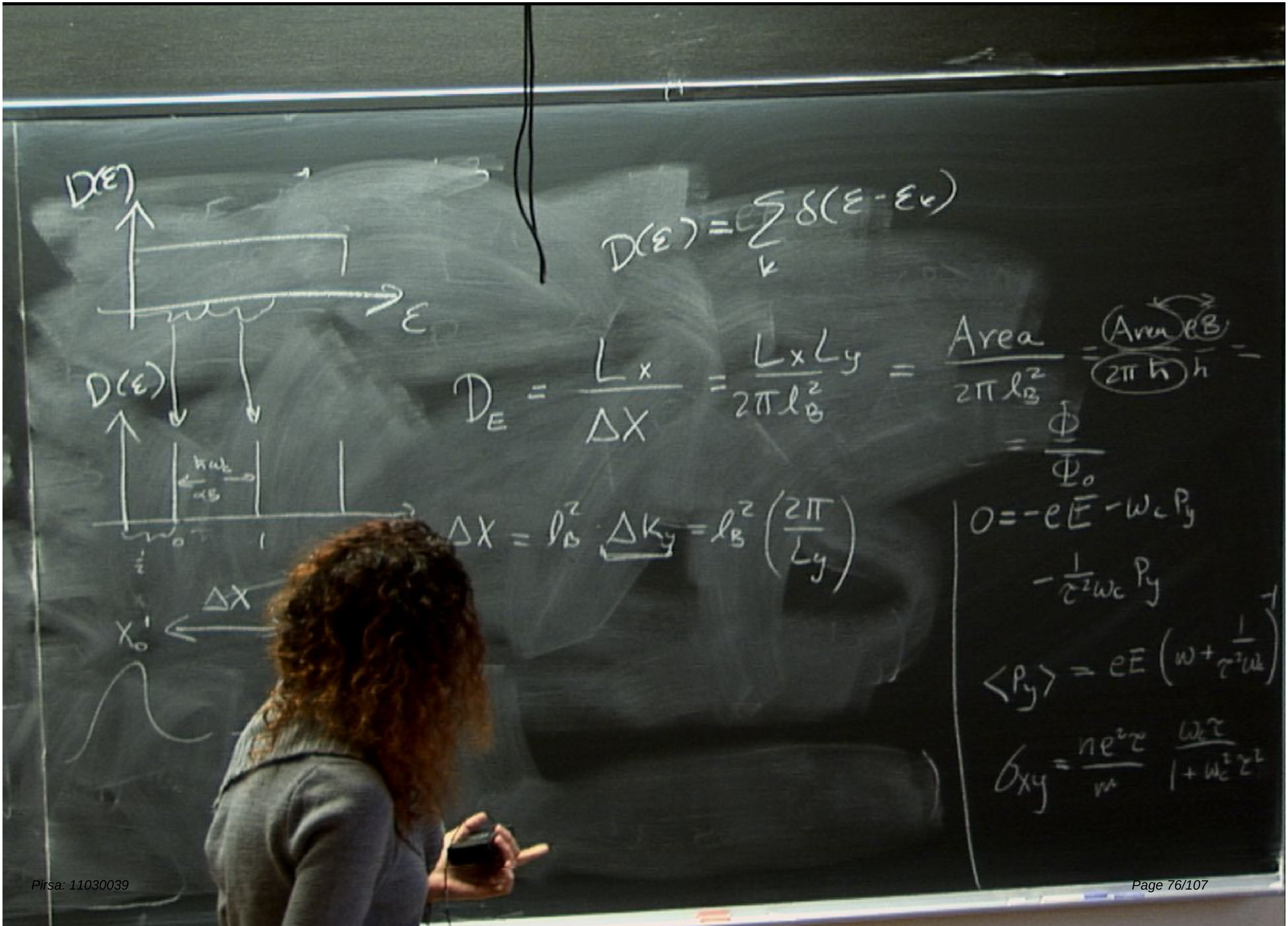
$$\sigma_{xy} = \frac{ne^2\tau}{m} \frac{\omega \ldots}{1 + \ldots}$$

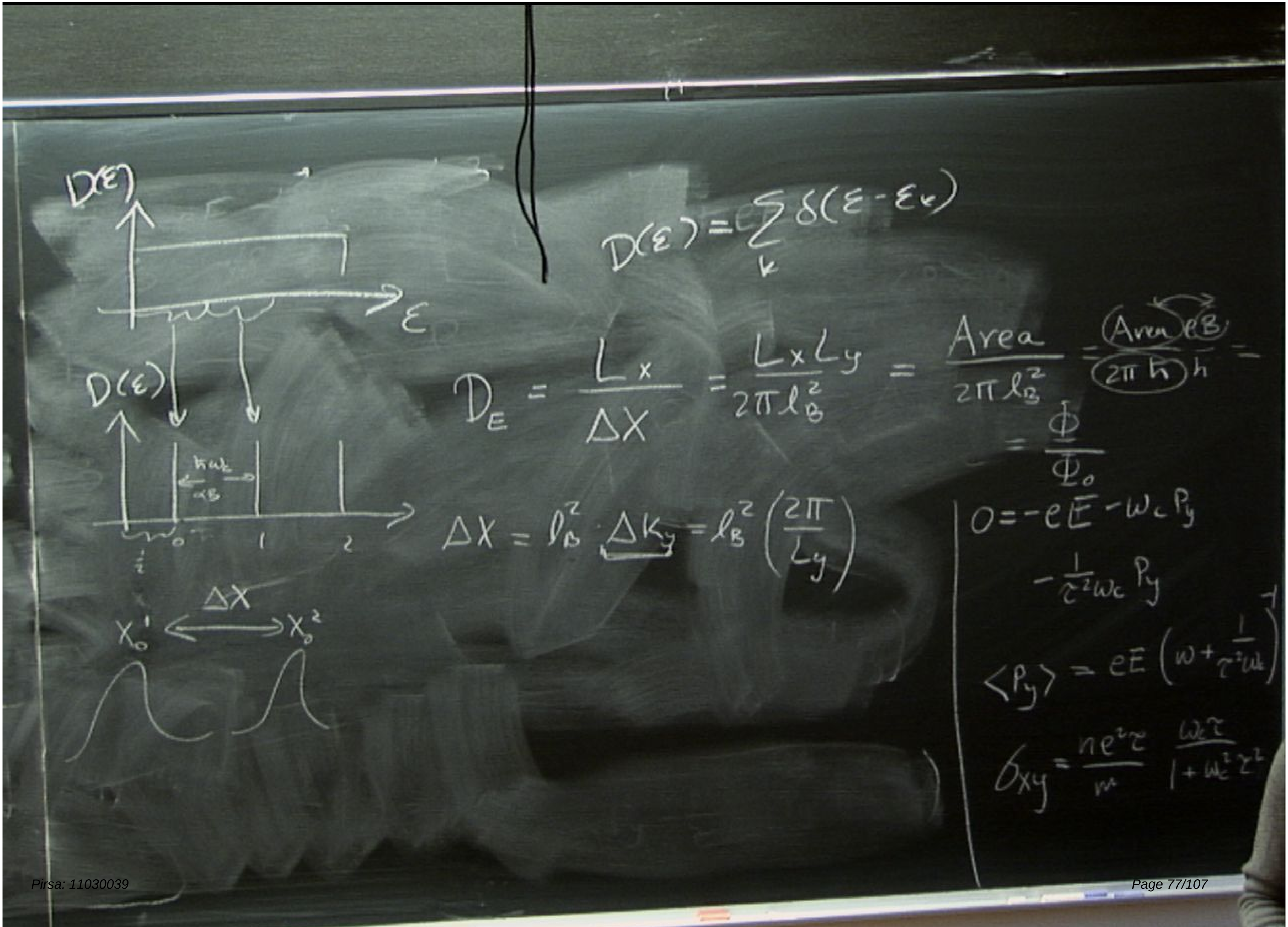

D(ε) = Σ_k δ(ε - ε_k)
D_E = L_x / ΔX
ΔX = l_B^2 ΔK = l_B^2 (2π / L_y)
ħω_c

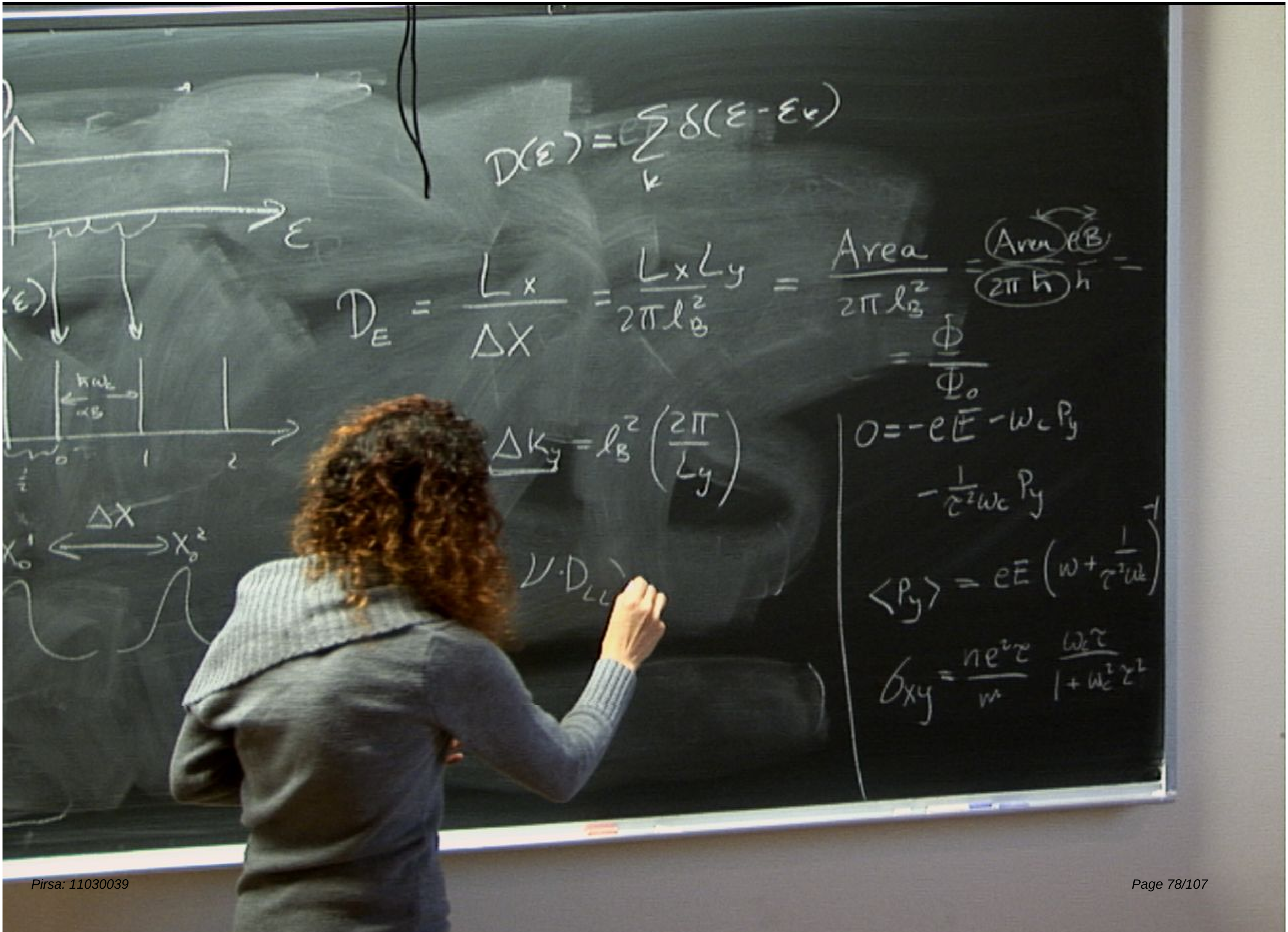

D(ε) = Σ_k δ(ε - ε_k)
D_E = Lx / ΔX = Lx / 2πl
ħω_c
∝B
ΔX
0 = -eE - ω_c P_y
⟨P_y⟩ = eE
σ_xy = ne²τ / m

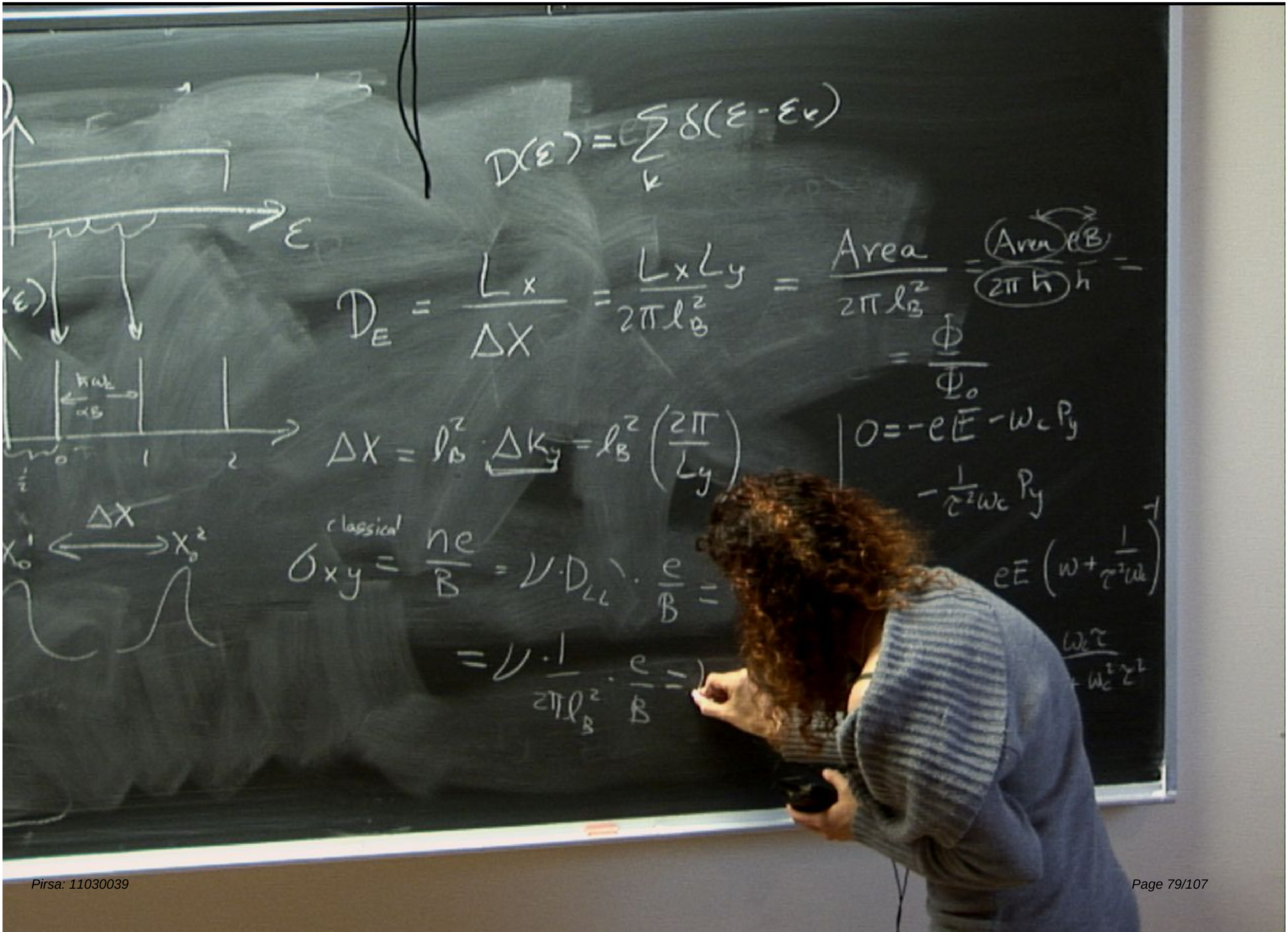

D(ε) = Σ_k δ(ε - ε_k)
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2 = Area e / 2π ħ
ΔX = l_B^2 ΔK_y
D(ε)
ε
ħω_c
∝B
ΔX
σ_xy = ne^2τ / m

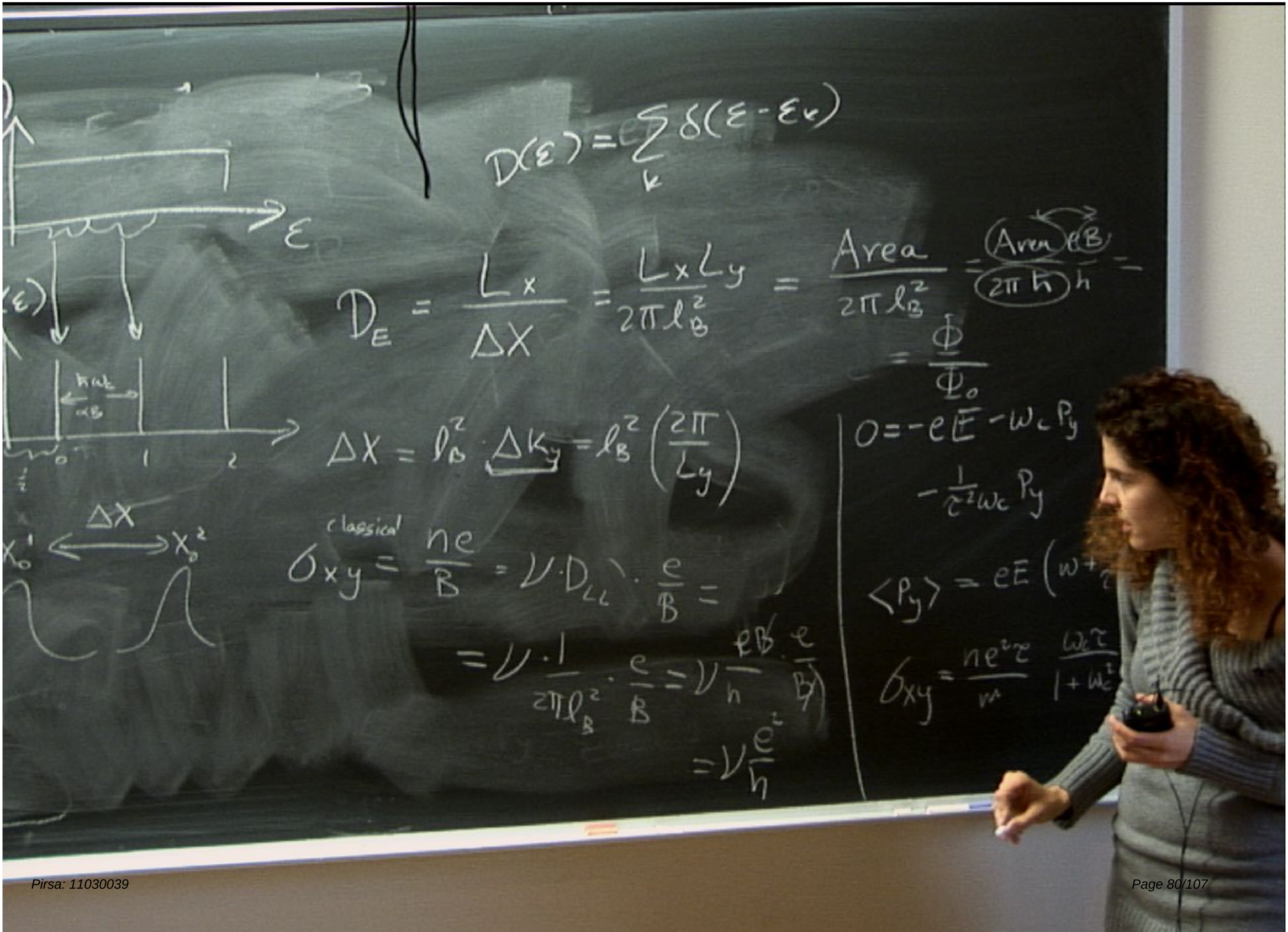

D(ε)
ε
D(ε)
ħω_c
∝B
0
1
2
ΔX
X_0^1
X_0^2
D(ε) = Σ_k δ(ε - ε_k)
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2 = Area eB / 2π ħ h
ΔX = l_B^2 ΔK_y
0 = -eE - ω_c P_y - 1/(τ^2 ω_c) P_y
⟨P_y⟩ = eE (ω + 1/(τ^2 ω_c))^-1
σ_xy = ne^2τ/m · ω_c τ / (1 + ω_c^2 τ^2)

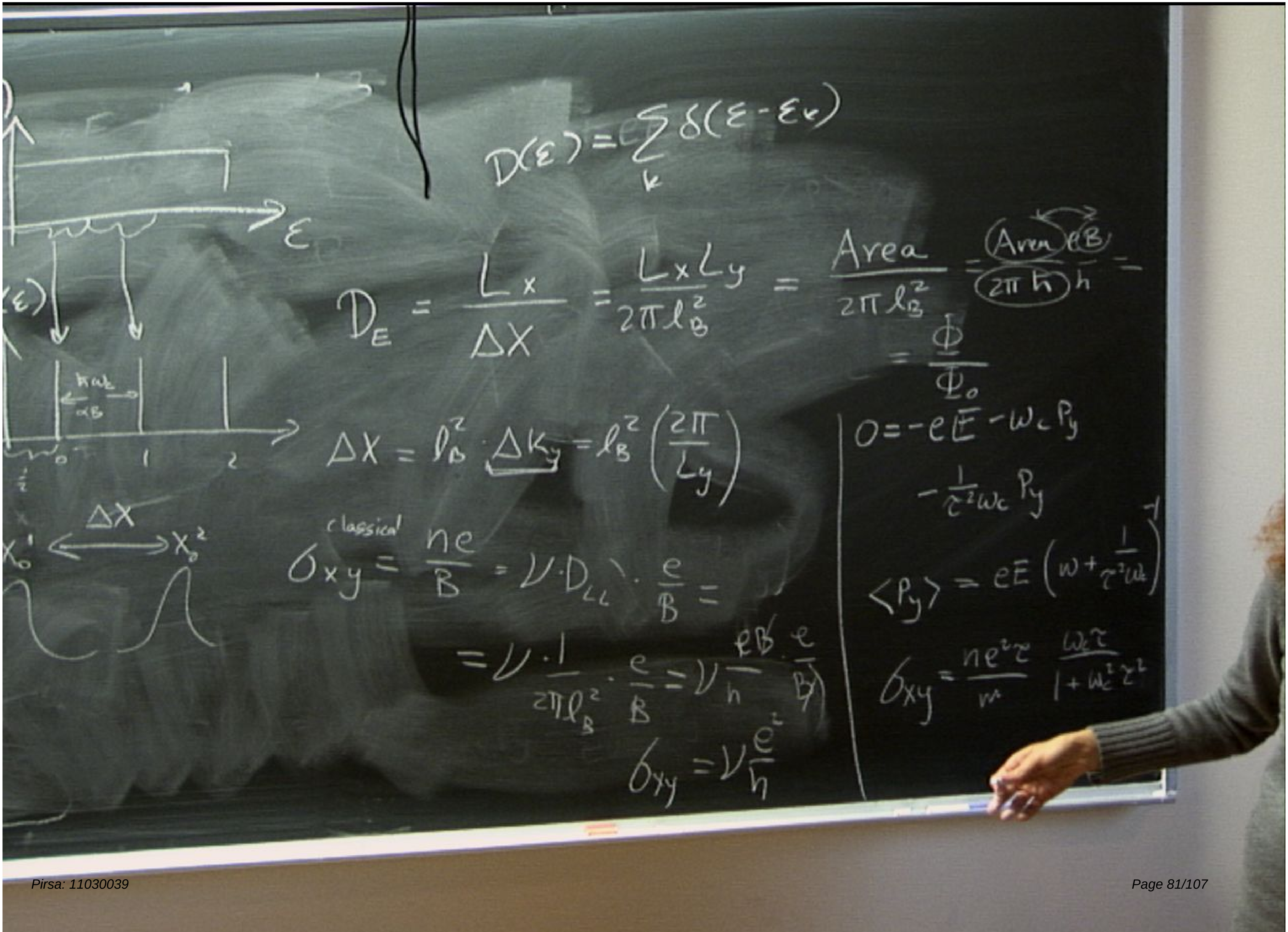

D(ε)
ε
D(ε) = Σ_k δ(ε - ε_k)
D(ε)
ħω_c
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2 = Area eB / 2πħ h
= Φ / Φ_0
ΔX = l_B^2 Δk_y = l_B^2 (2π / L_y)
ΔX
X_0'
0 = -eE - ω_c p_y - 1/(τ^2 ω_c) p_y
⟨p_y⟩ = eE (ω + 1/(τ^2 ω_c))^-1
σ_xy = ne^2τ/m · ω_cτ / (1 + ω_c^2 τ^2)

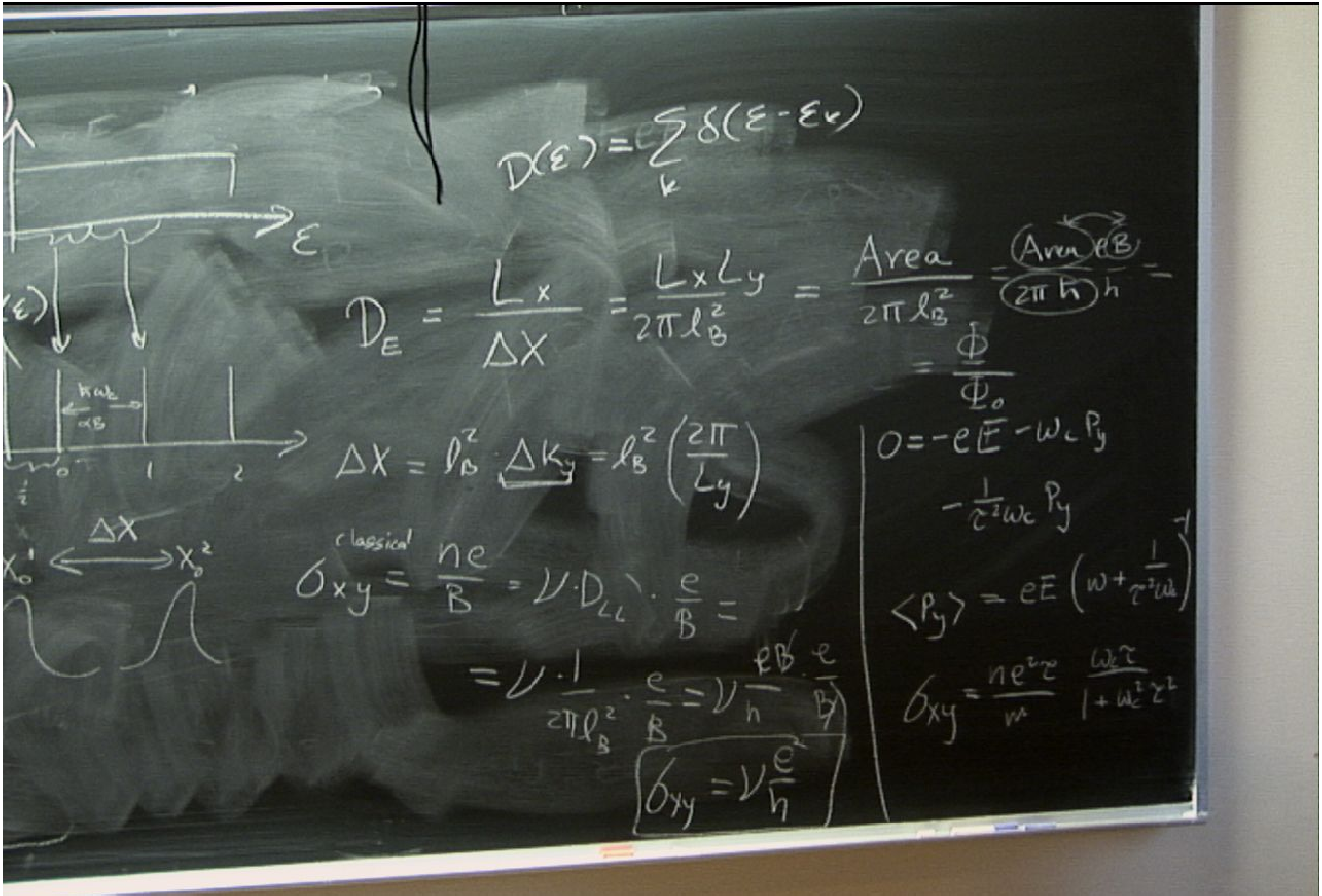

D(ε)
ε
ħω_c
D(ε) = Σ_k δ(ε − ε_k)
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2
= Φ / Φ_0
ΔX = l_B^2 ΔK_y = l_B^2 (2π / L_y)
ΔX
X_0^1
X_0^2
0 = −eE − ω_c P_y
− 1/(τ^2 ω_c) P_y
⟨P_y⟩ = eE (ω + 1/(τ^2 ω_c))^{-1}
σ_xy = (ne^2 τ / m) (ω_c τ / (1 + ω_c^2 τ^2))

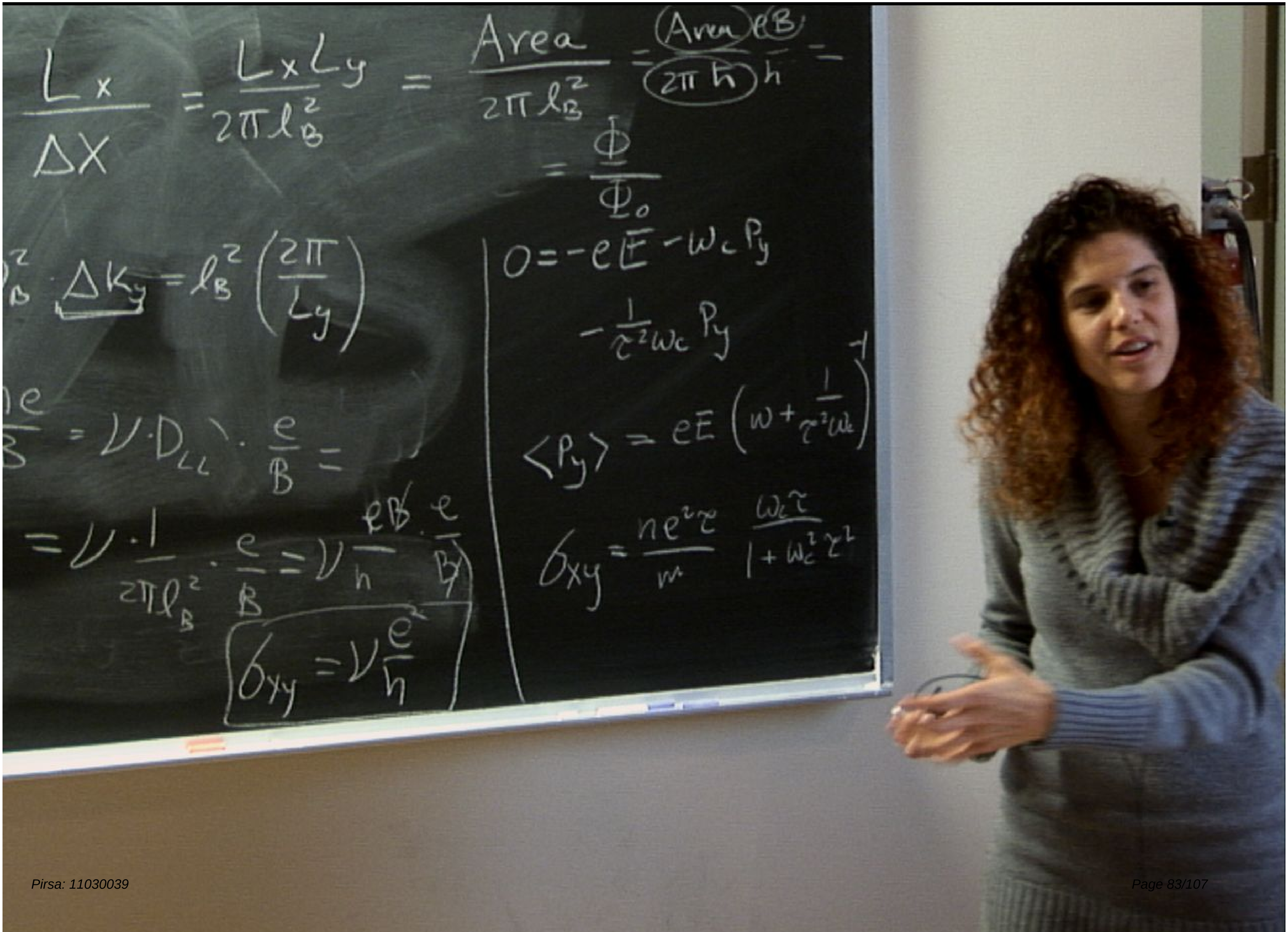

D(ε) = Σ_k δ(ε − ε_k)
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2
ΔK_y = l_B^2 (2π / L_y)
O = −eE − ω_c P_y − (1/τ^2 ω_c) P_y
⟨P_y⟩ = eE (ω + 1/τ^2 ω_c)^{-1}
σ_xy = (ne^2 τ / m) (ω_c τ / 1 + ω_c^2 τ^2)
ΔX

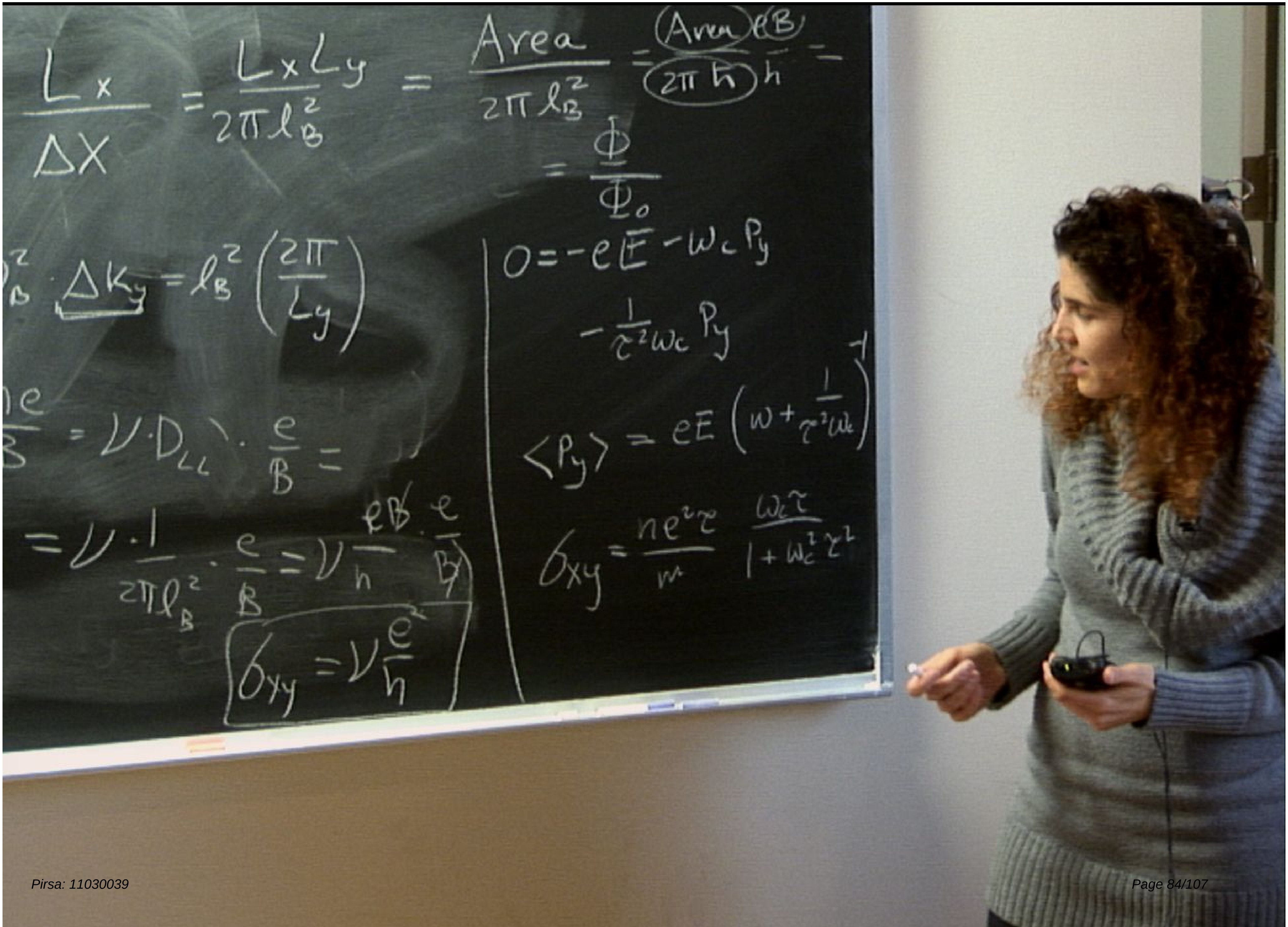

D(ε) = Σ_k δ(ε − ε_k)
ε
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2 = (Area eB) / (2π ħ) h
= Φ / Φ_0
ΔX = l_B^2 ΔK_y = l_B^2 (2π / L_y)
ΔX
classical
σ_xy = ne / B = ν · D_LL · e / B =
= ν · 1 / 2π l_B^2 · e / B =
0 = −eE − ω_c P_y
− 1 / τ^2 ω_c P_y
eE (ω + 1 / τ^2 ω_c)


D(ε) = Σ_k δ(ε - ε_k)
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2 = (Area eB) / (2π ħ) h
= Φ / Φ_0
ΔX = l_B^2 Δk_y = l_B^2 (2π / L_y)
ħω_c
∝B
ΔX
X_0^1 X_0^2
classical
σ_xy = ne / B = ν · D_LL · e / B =
= ν · 1 / 2π l_B^2 · e / B = ν eB / h · e / B
= ν e^2 / h
0 = -eE - ω_c P_y
- 1 / τ^2 ω_c P_y
⟨P_y⟩ = eE (ω +
σ_xy = ne^2τ / m · ω_cτ / 1 + ω_c^2

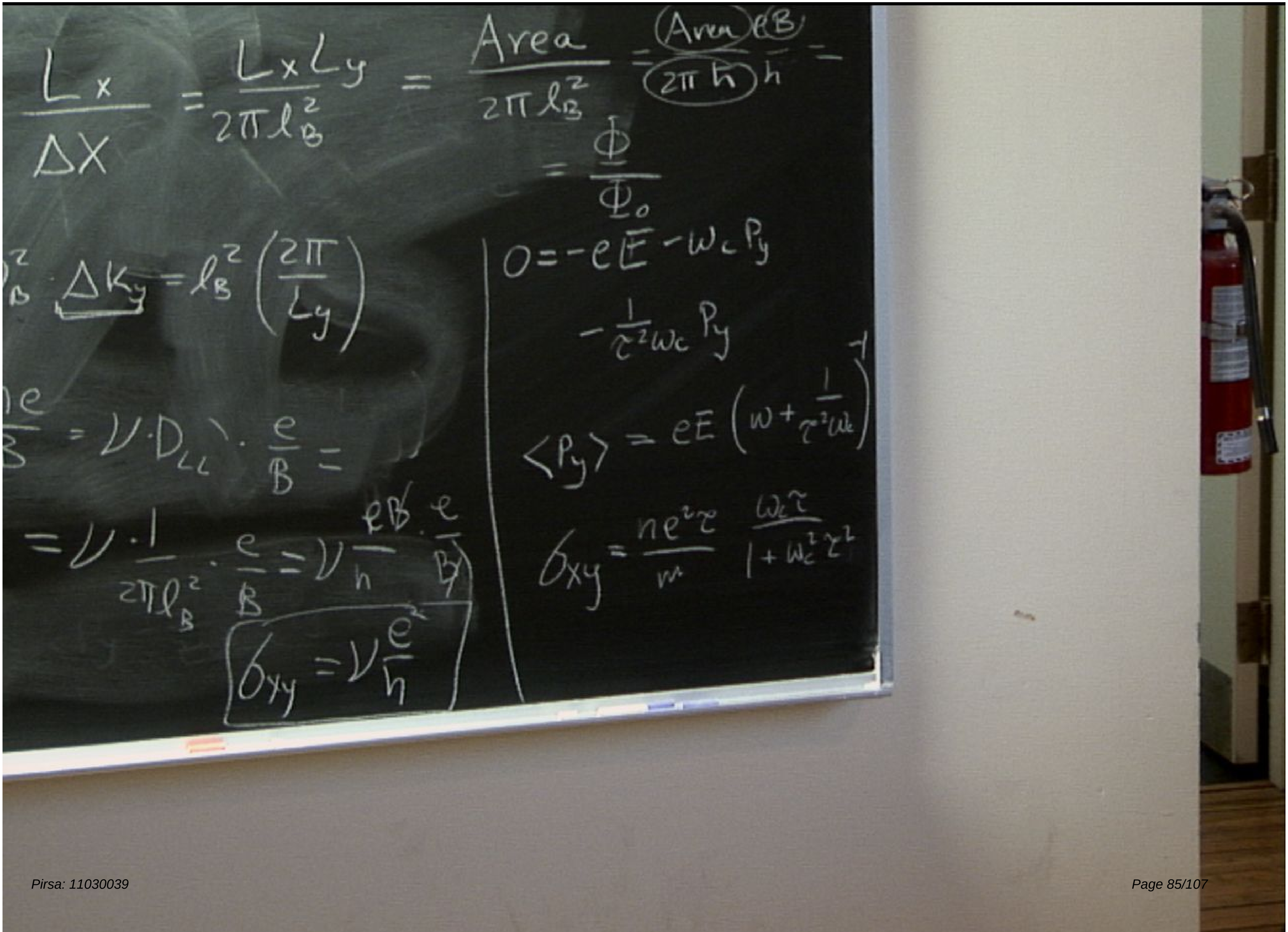

D(ε) = Σ_k δ(ε − ε_k)
D_E = L_x / ΔX = L_x L_y / 2π l_B² = Area / 2π l_B² = (Area eB) / (2π ħ) h
= Φ / Φ_0
ΔX = l_B² Δk_y = l_B² (2π / L_y)
classical
σ_xy = ne / B = ν · D_LL · e / B =
= ν · 1 / 2π l_B² · e / B = ν eB / h · e / B
σ_xy = ν e² / h
0 = −eE − ω_c P_y
− 1 / τ² ω_c P_y
⟨P_y⟩ = eE (ω + 1 / τ² ω_c)^−1
σ_xy = ne²τ / m · ω_c τ / (1 + ω_c² τ²)
ΔX
ε

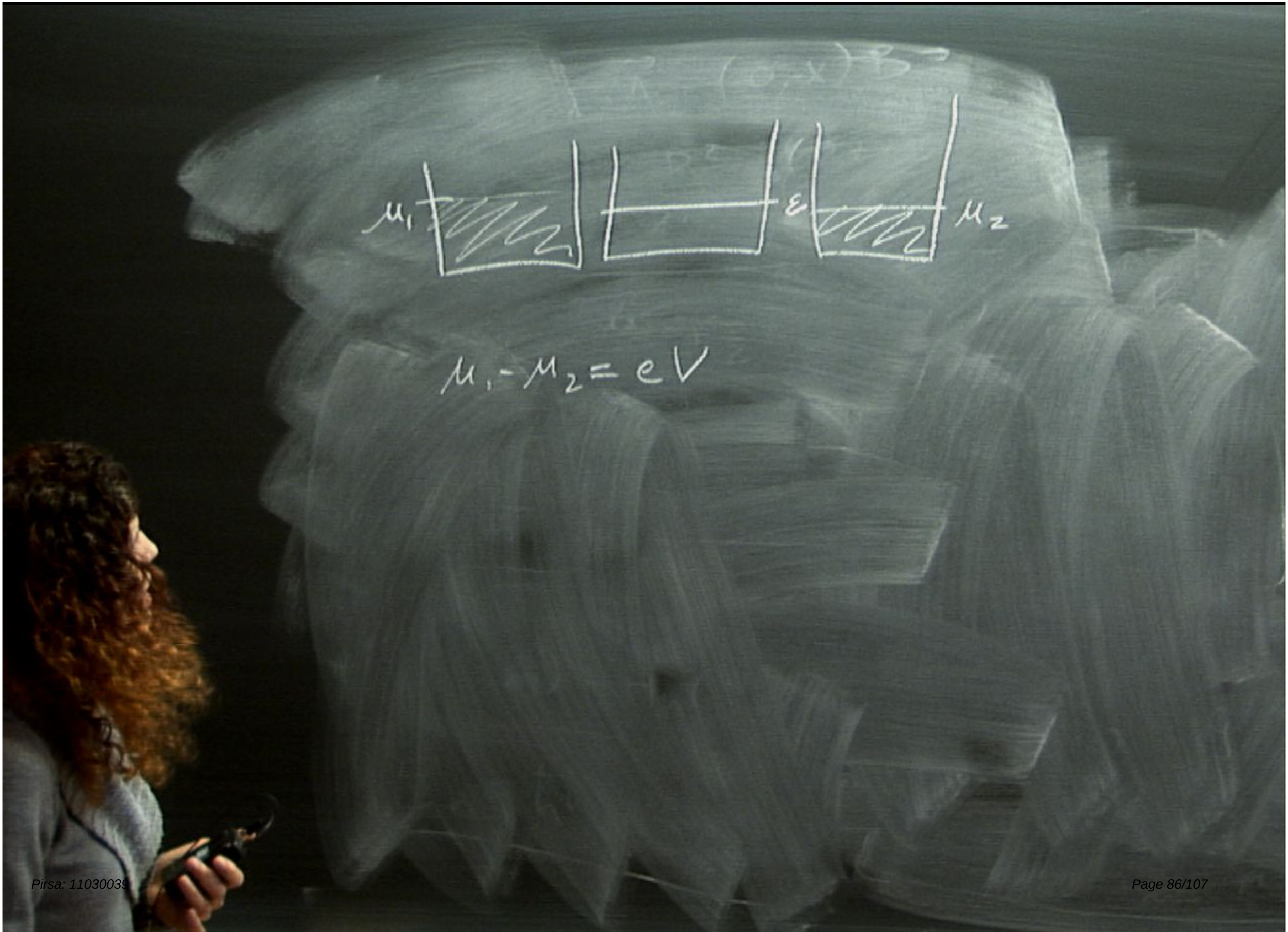

D(ε) = Σ_k δ(ε - ε_k)
ε
D_E = L_x / ΔX = L_x L_y / 2π l_B^2 = Area / 2π l_B^2 = (Area eB) / (2π ħ) h =
= Φ / Φ_0
ħω_c
∝B
0
1
2
ΔX = l_B^2 ΔK_y = l_B^2 (2π / L_y)
ΔX
X_0^1 X_0^2
classical
σ_xy = ne / B = ν · D_LL · e / B =
= ν · 1 / 2π l_B^2 · e / B = ν eB / h · e / B
σ_xy = ν e / h
0 = -eE - ω_c P_y
- 1 / τ^2 ω_c P_y
⟨P_y⟩ = eE (ω + 1 / τ^2 ω_c)^-1
σ_xy = ne^2 τ / m · ω_c τ / (1 + ω_c^2 τ^2)

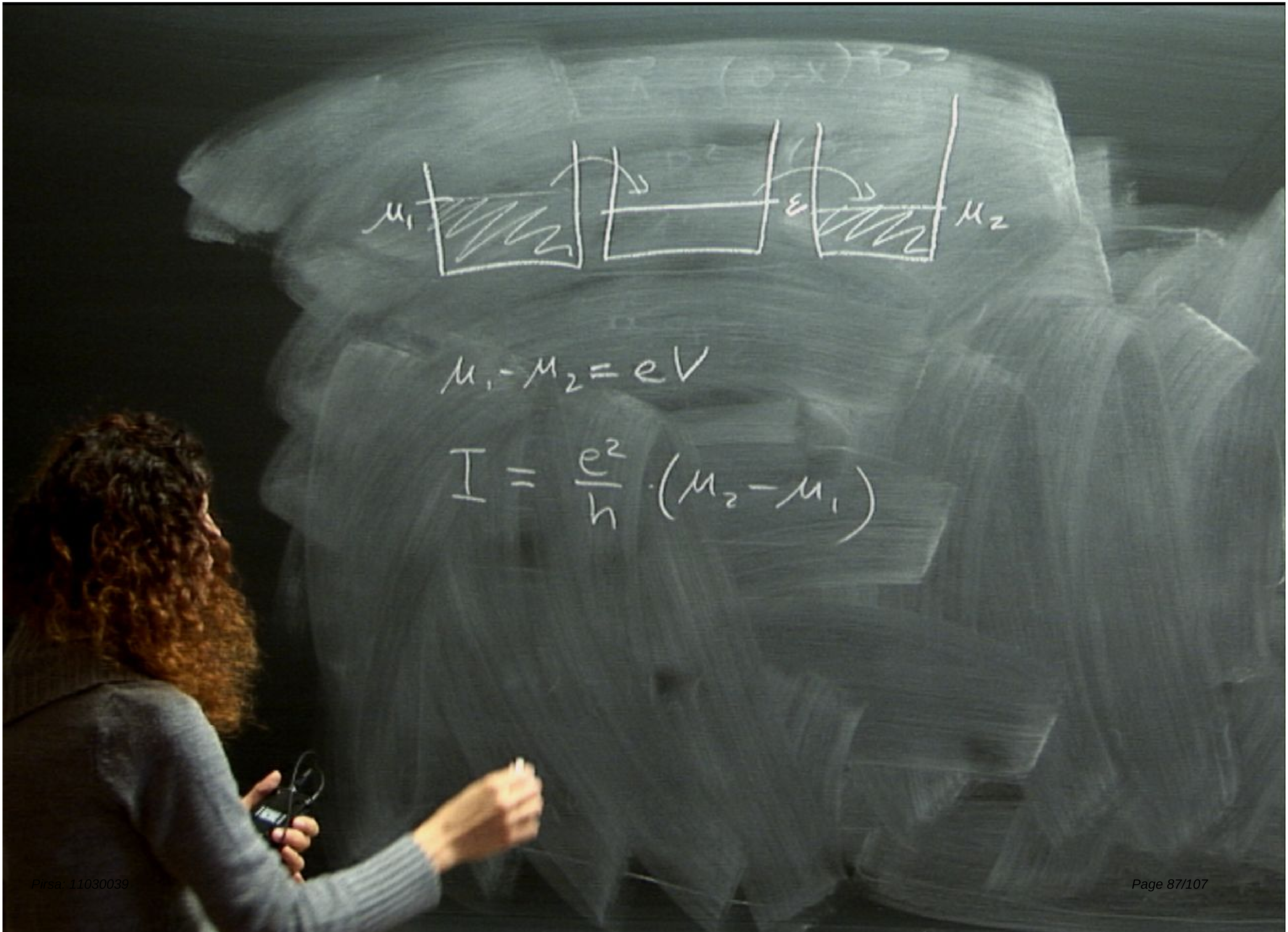

Lx / ΔX = LxLy / 2πl_B^2 = Area / 2πl_B^2 = (Area eB) / (2πħ) h =
= Φ / Φ_0
l_B^2 · ΔK_y = l_B^2 (2π / L_y)
0 = −eE − ω_c P_y − (1 / τ^2 ω_c) P_y
⟨P_y⟩ = eE (ω + 1 / τ^2 ω_c)^−1
σ_xy = (ne^2 τ / m) (ω_c τ / 1 + ω_c^2 τ^2)
= ν · 1 / 2πl_B^2 · e / B = ν eB / h · e / B
σ_xy = ν e^2 / h

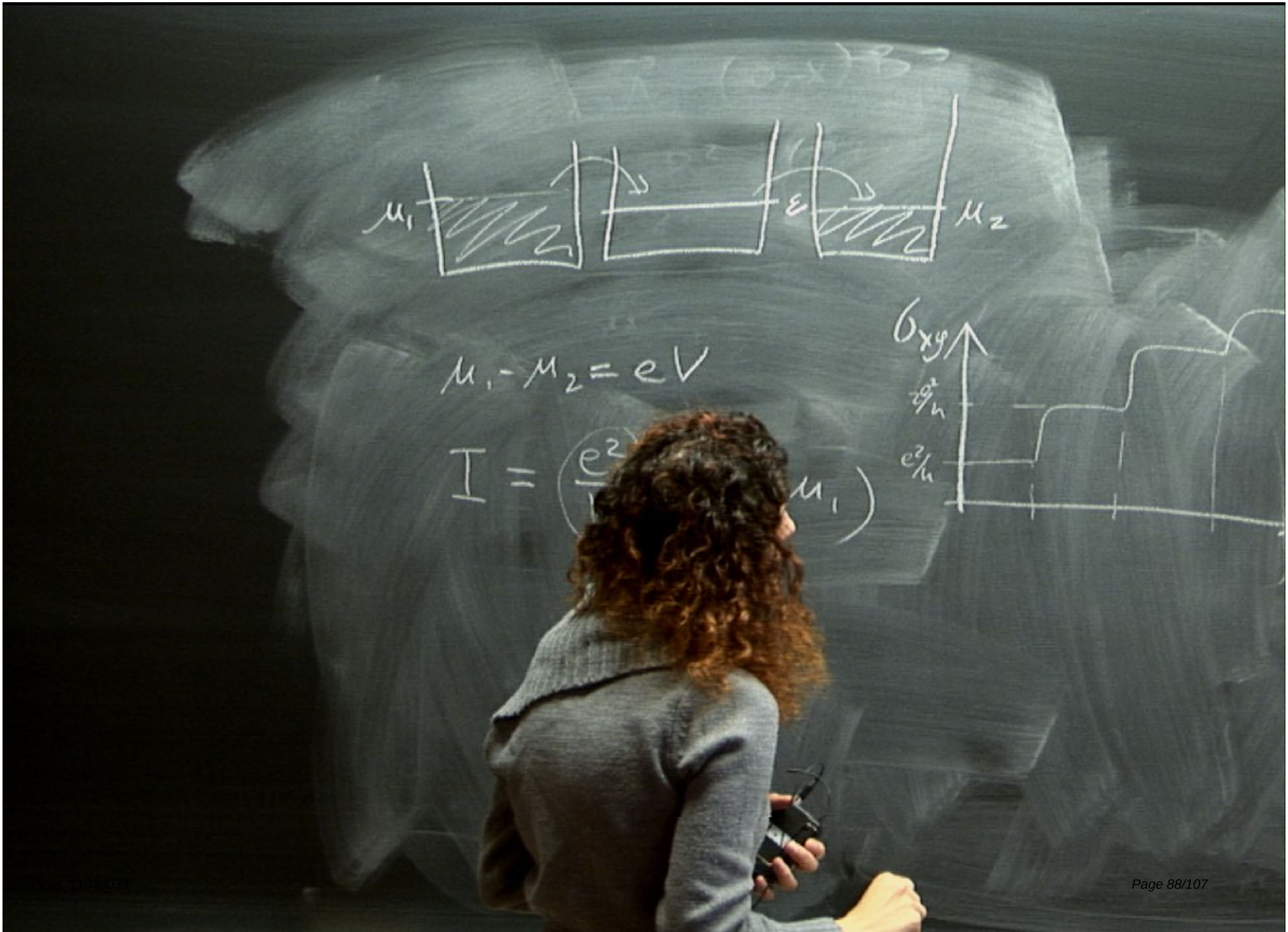


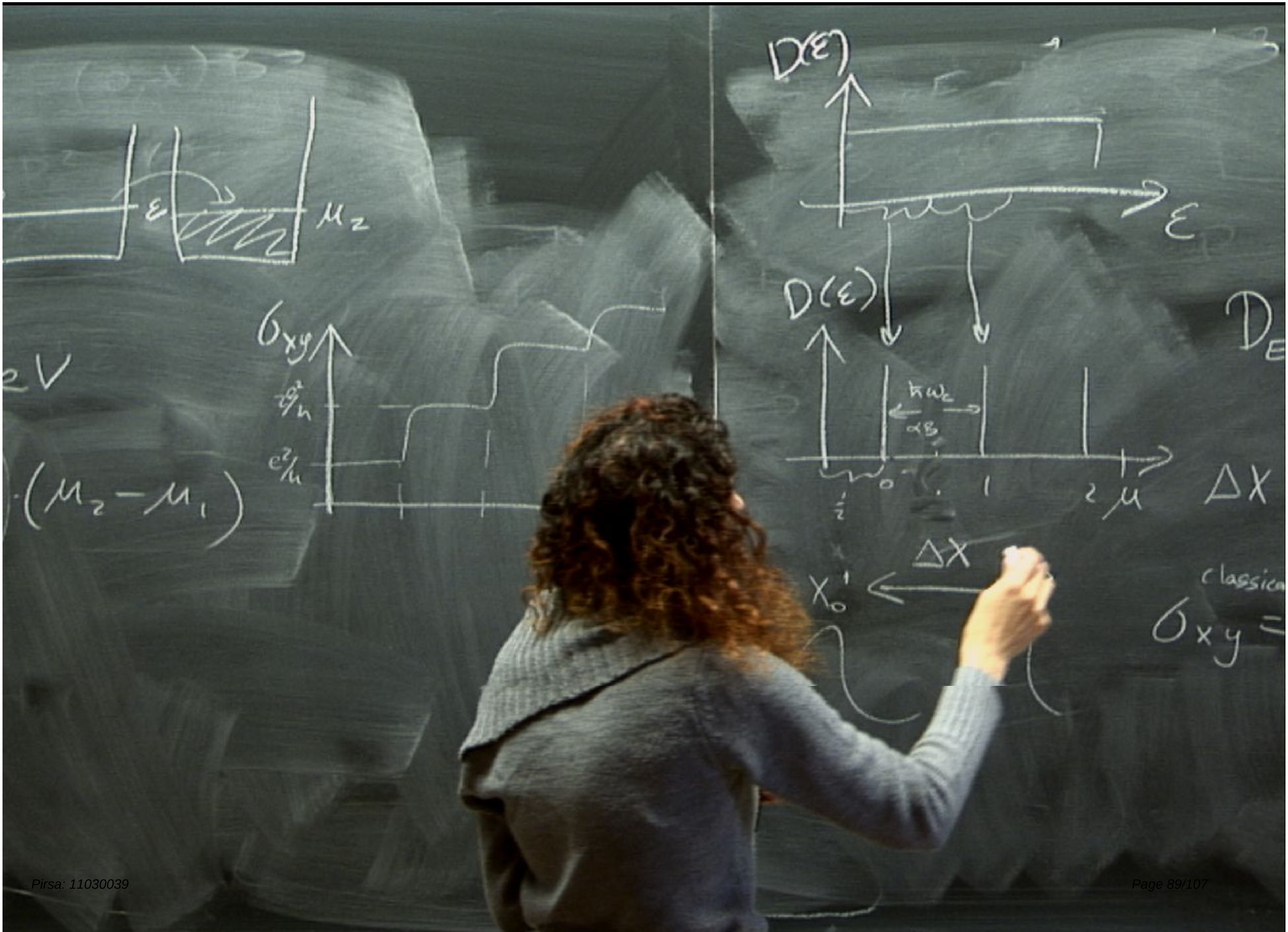
Lx / ΔX = LxLy / 2πl_B² = Area / 2πl_B² = (Area eB) / (2πħ) h
= Φ / Φ₀
0 = −eE − ω_c P_y − (1/τ²ω_c) P_y
⟨P_y⟩ = eE (ω + 1/τ²ω_c)⁻¹
σ_xy = (ne²τ/m) ω_cτ / (1 + ω_c²τ²)
σ_xy = ν e²/h


Lx / ΔX = LxLy / 2πℓB² = Area / 2πℓB² = (Area eB) / (2πħ h) =
= Φ / Φ0
0 = −eE − ωc Py − 1/(τ²ωc) Py
⟨Py⟩ = eE (ω + 1/(τ²ωc))⁻¹
σxy = ne²τ/m · ωcτ/(1 + ωc²τ²)
σxy = ν e²/h

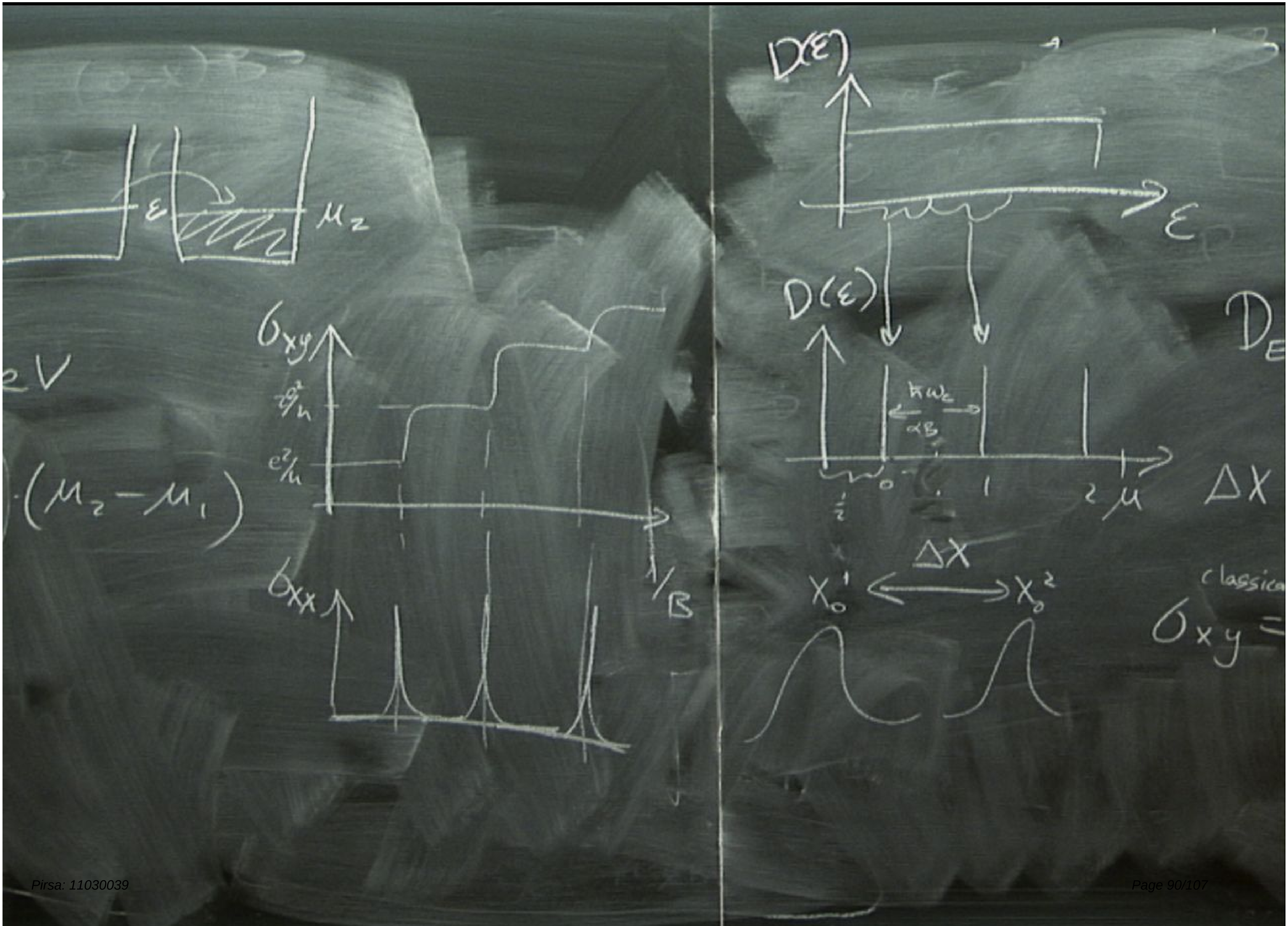

μ_1
ε
μ_2
$\mu_1 - \mu_2 = eV$

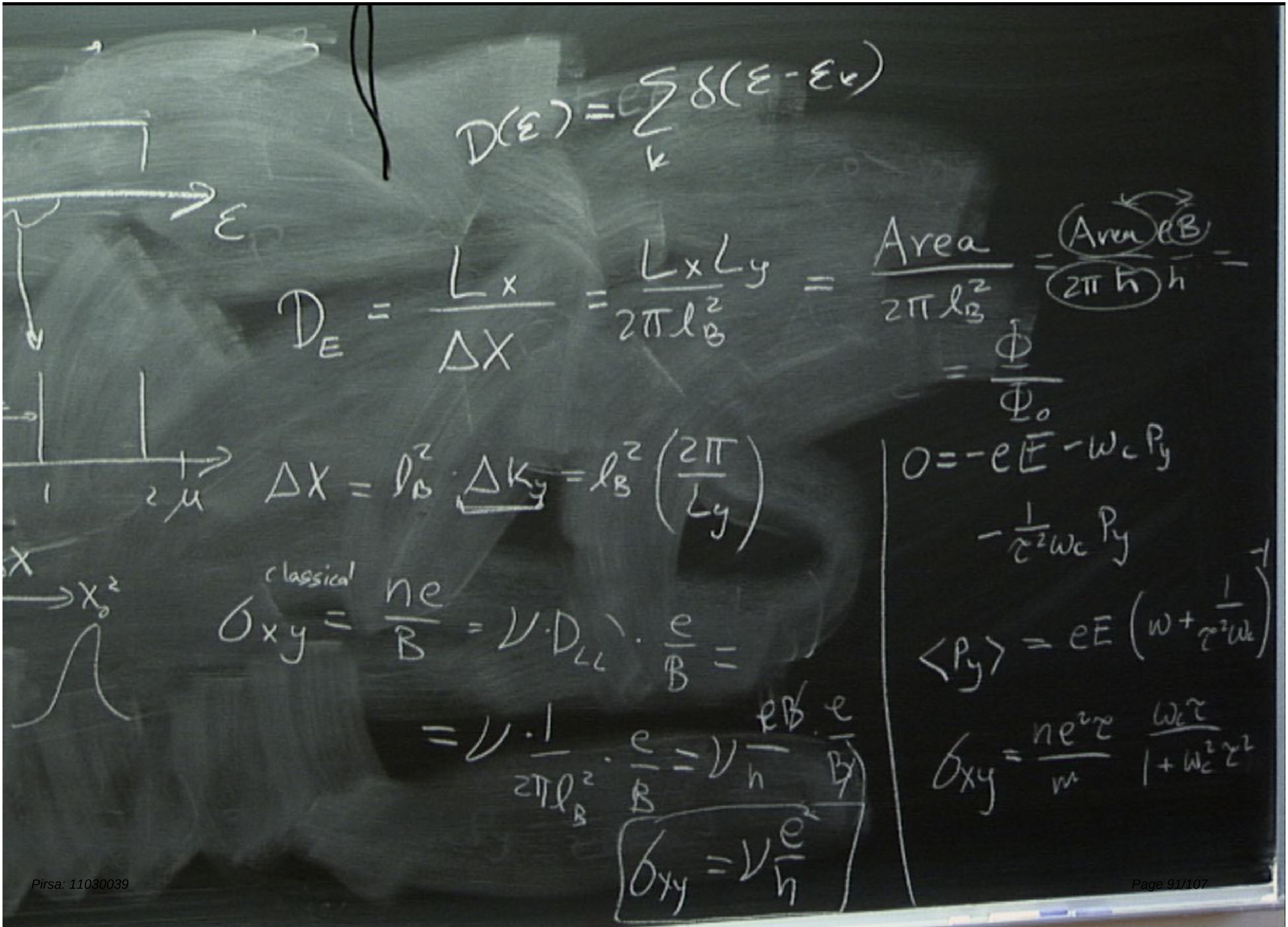

μ1
ε
μ2
μ1 - μ2 = eV
I = e²/h · (μ2 - μ1)

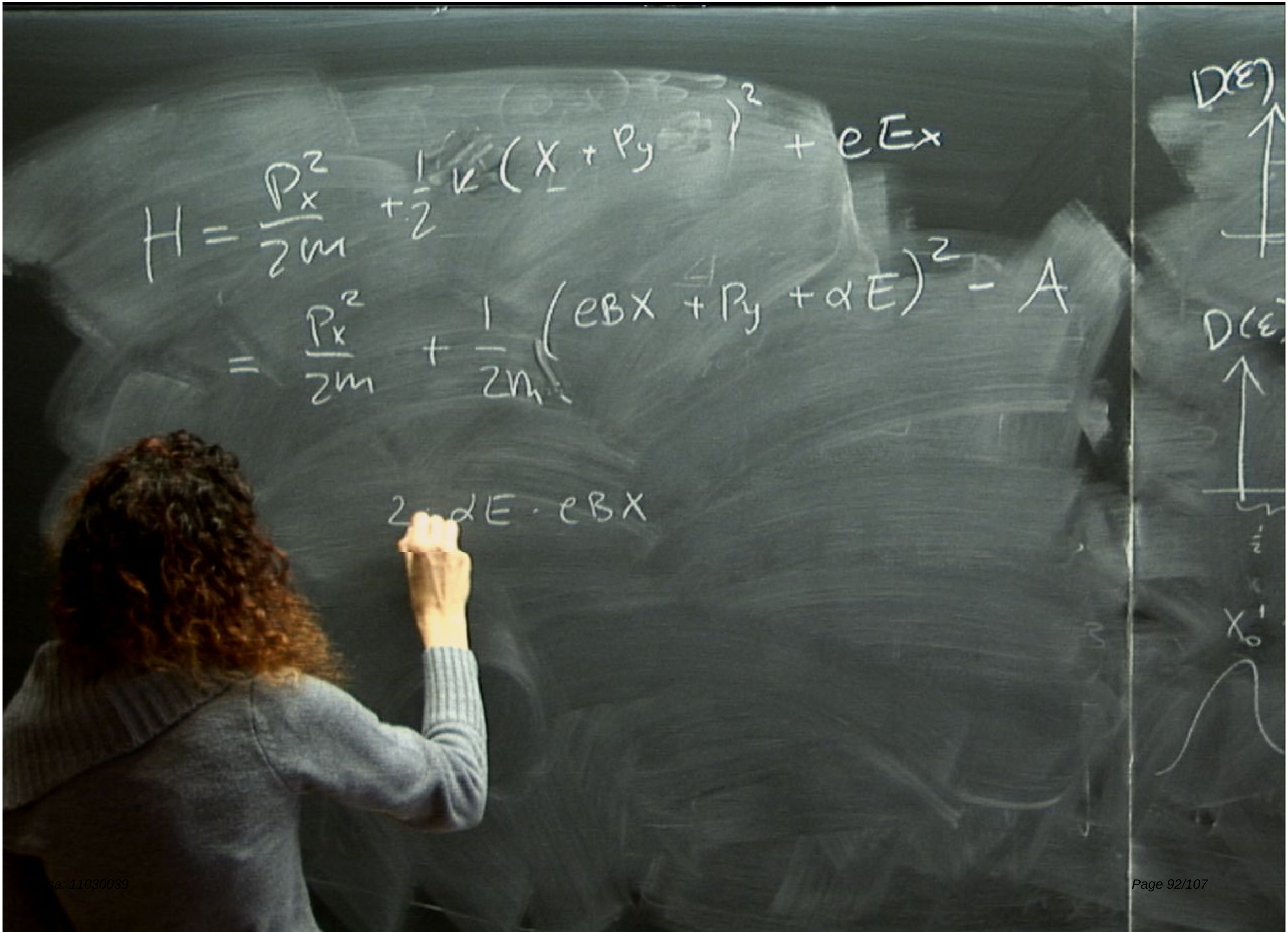

μ1
ε
μ2
μ1 - μ2 = eV
σxy
2e²/h
e²/h

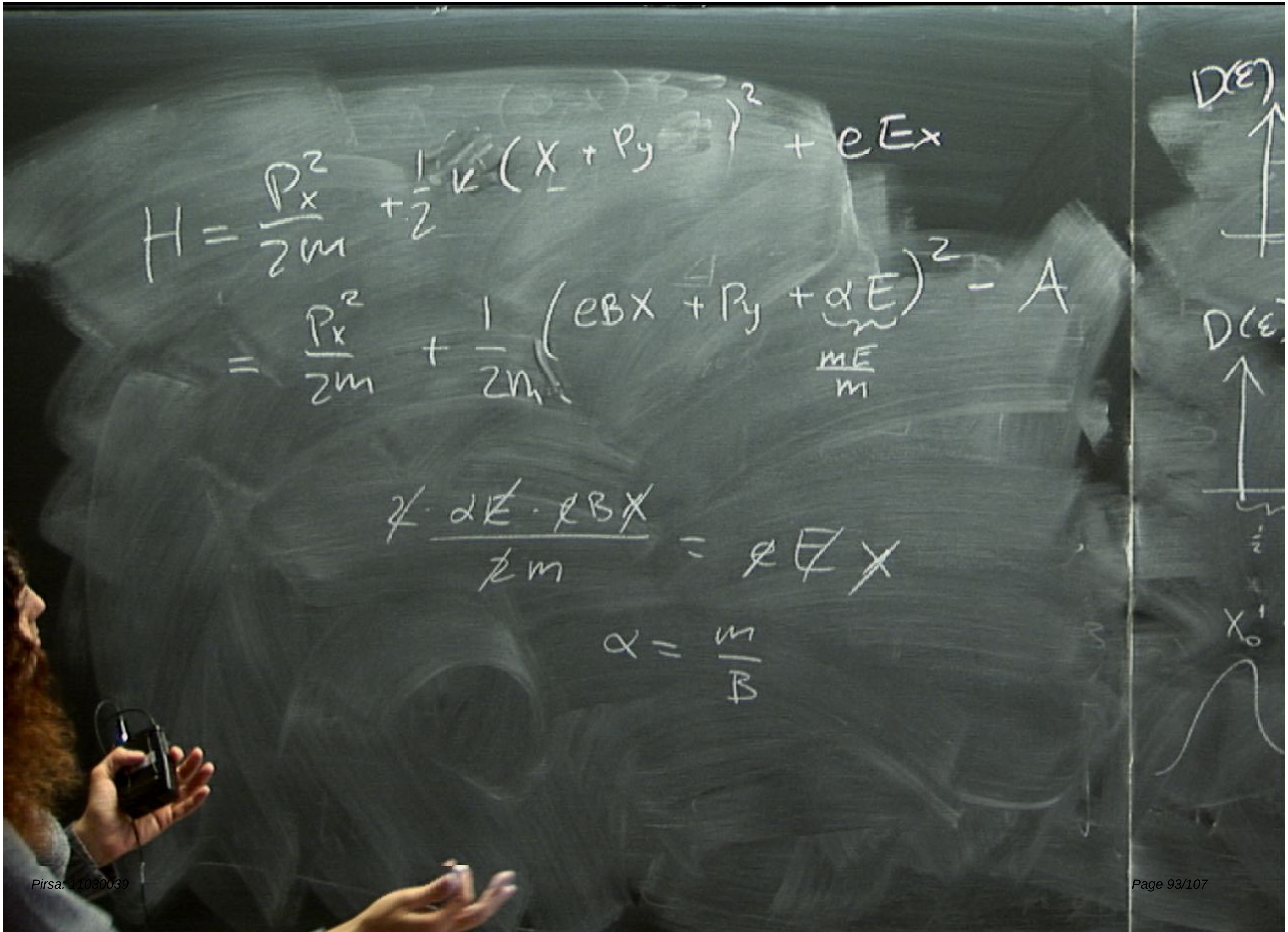


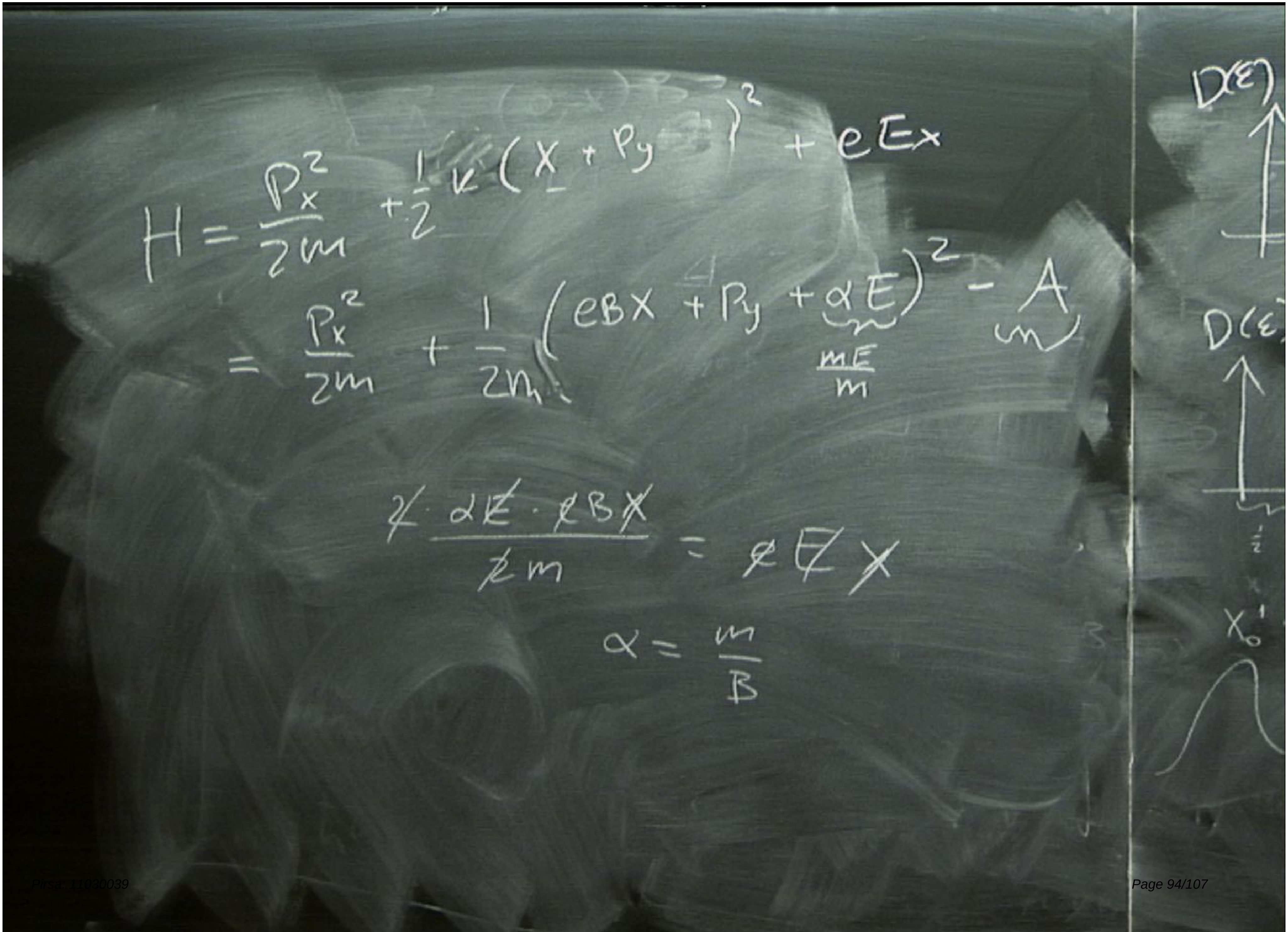
D(ε)
ε
μ2
D(ε)
ħωc
∝B
σxy
e²/h
2e²/h
eV
·(μ2−μ1)
0
1
2
μ
ΔX
X0'
ΔX
classica
σxy =


D(ε)
ε
μ2
eV
(μ2 − μ1)
σxy
e²/h
1/B
σxx
ħωc
∝B
μ
ΔX
X0¹
X0²
σxy =

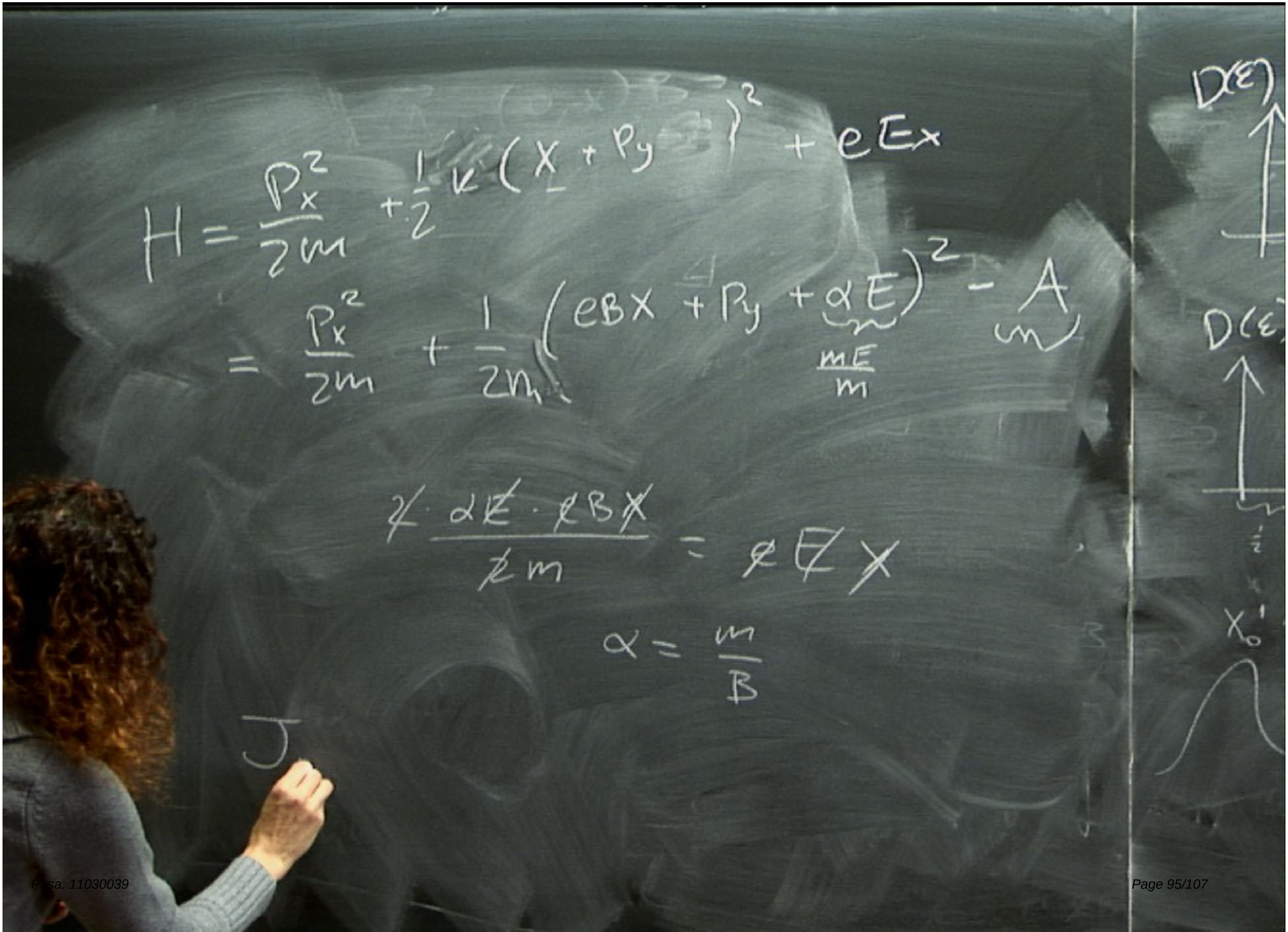

D(ε) = Σ_k δ(ε − ε_k)
D_E = L_x / ΔX = L_x L_y / 2π l_B² = Area / 2π l_B² = (Area) eB / (2π ħ) h =
= Φ / Φ_0
ΔX = l_B² · Δk_y = l_B² (2π / L_y)
0 = −eE − ω_c P_y − (1 / τ² ω_c) P_y
⟨P_y⟩ = eE (ω + 1 / τ² ω_c)^−1
σ_xy = (ne²τ / m) · ω_c τ / (1 + ω_c² τ²)
classical
σ_xy = ne / B = ν · D_LL · e / B =
= ν · 1 / 2π l_B² · e / B = ν eB / h · e / B
σ_xy = ν e² / h
ε
μ

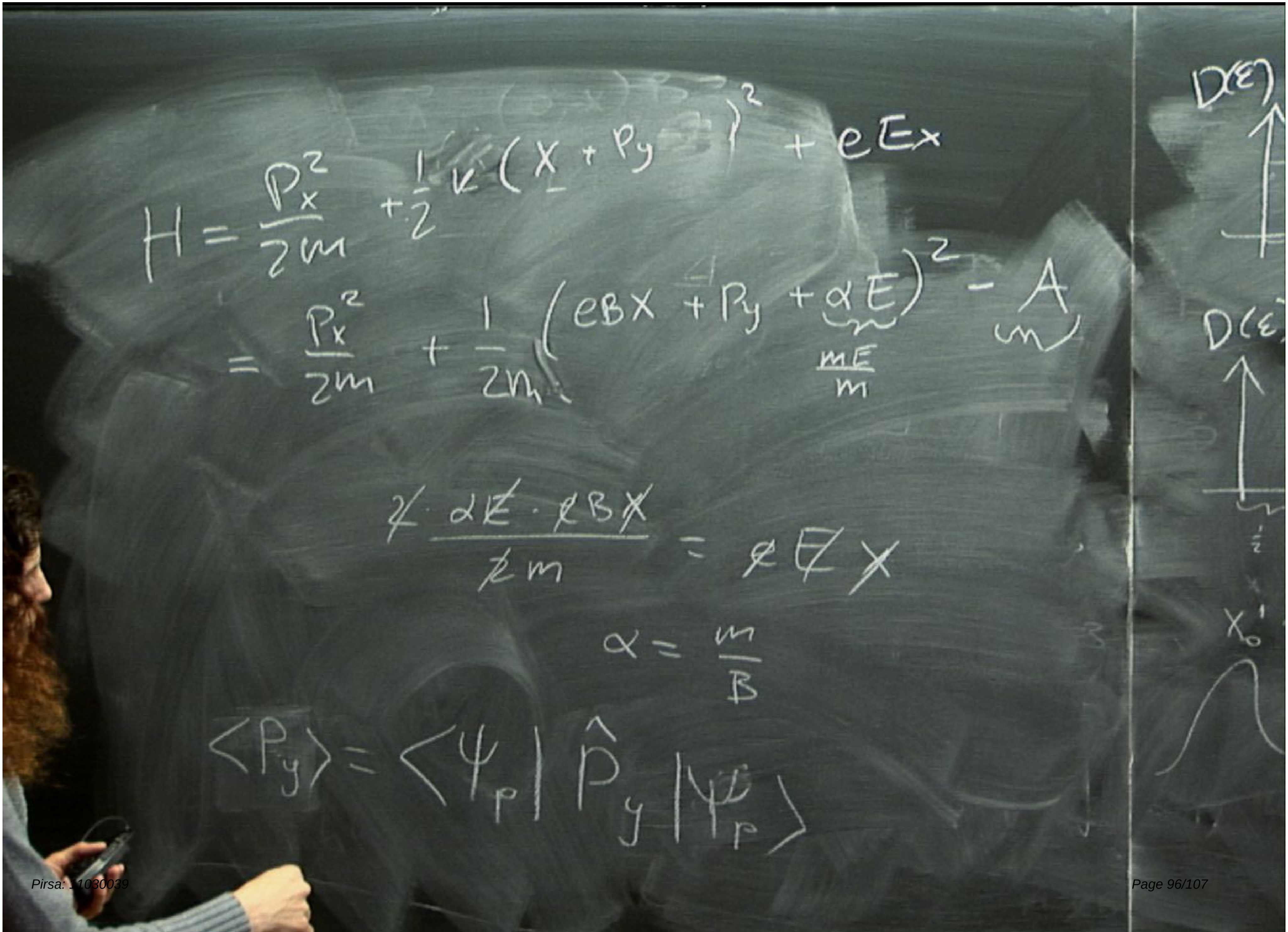

H = Px^2/2m + 1/2 k (X + Py)^2 + eEx
= Px^2/2m + 1/2m (eBX + Py + αE)^2 - A
2 αE · eBX
D(ε)
D(ε)
X0'


H = P_x^2 / 2m + 1/2 k (X + P_y)^2 + eEx
= P_x^2 / 2m + 1/2m (eBX + P_y + αE)^2 - A
mE / m
α = m / B
D(ε)
D(ε)
X_0



$H = \frac{P_x^2}{2m} + \frac{1}{2}k(X + P_y \ldots)^2 + eEx$
$= \frac{P_x^2}{2m} + \frac{1}{2m}(eBX + P_y + \alpha E)^2 - A$
$\frac{mE}{m}$
$\frac{2 \cdot \alpha E \cdot eBX}{2m} = eEX$
$\alpha = \frac{m}{B}$
D(ε)
D(ε
X_0'


H = Px²/2m + 1/2 k(X + Py ...)² + eEx
= Px²/2m + 1/2m (eBX + Py + αE)² − A
mE/m
α = m/B
J
D(ε)
D(ε)


H = P_x^2/2m + 1/2 k (X + P_y ...)^2 + eEx
= P_x^2/2m + 1/2m (eBX + P_y + αE)^2 − A
mE/m
2·αE·eBX/2m = eEX
α = m/B
⟨P_y⟩ = ⟨ψ_p| P̂_y |ψ_p⟩
D(ε)
D(ε
X_0'

$$H = \frac{p_x^2}{2m} + \frac{1}{2}k\left(x + p_y \ldots\right)^2 + eEx$$

$$= \frac{p_x^2}{2m} + \frac{1}{2m}\Big(eBx + \underbrace{p_y}_{\hbar k} + \underbrace{\alpha E}_{\frac{mE}{m}}\Big)^2 - \underbrace{A}_{m}$$

$$\frac{\not{2}\cdot\alpha\not{E}\cdot\not{e}B\not{x}}{\not{2}m} = \not{e}\not{E}\not{x}$$

$$\alpha = \frac{m}{B}$$

$$\langle p_y\rangle = \langle\psi_p|\,\hat{P}_y\,|\psi_p\rangle = \langle\psi_k|(p_y - eA\ldots$$

D(ε)

D(ε

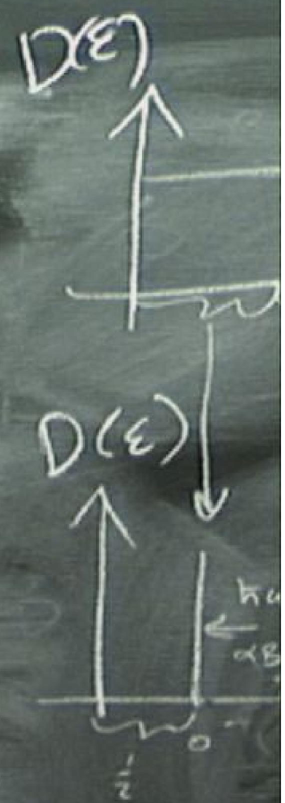
$$H = \frac{P_x^2}{2m} + \frac{1}{2}k\left(X + P_y \ldots\right)^2 + eEx$$

$$= \frac{P_x^2}{2m} + \frac{1}{2m}\left(eBX + \underbrace{P_y}_{\hbar K} + \underbrace{\alpha E}_{\frac{mE}{m}}\right)^2 - \underbrace{A}_{(m)}$$

$$\frac{2 \cdot \alpha E \cdot eBX}{2m} = eEX$$

$$\alpha = \frac{m}{B}$$

$$\langle P_y \rangle = \langle \Psi_p | \hat{P}_y | \Psi_p \rangle = \langle \Psi_k | (P_y - eA_y) | \Psi_k \rangle$$



$$\psi_k^{\tau} = e^{-\frac{(X + X_0 + X_1)^2}{2 l_B^2}}$$

$k l_B^2 \quad \mu \frac{E}{B}$

$\delta(\varepsilon - \ldots)$

k

$$x e^{-ax^2} dx = 0$$

$$= \frac{\text{Area}}{2\pi l_B^2} = \frac{(\text{Area}}{(2\pi \hbar}$$

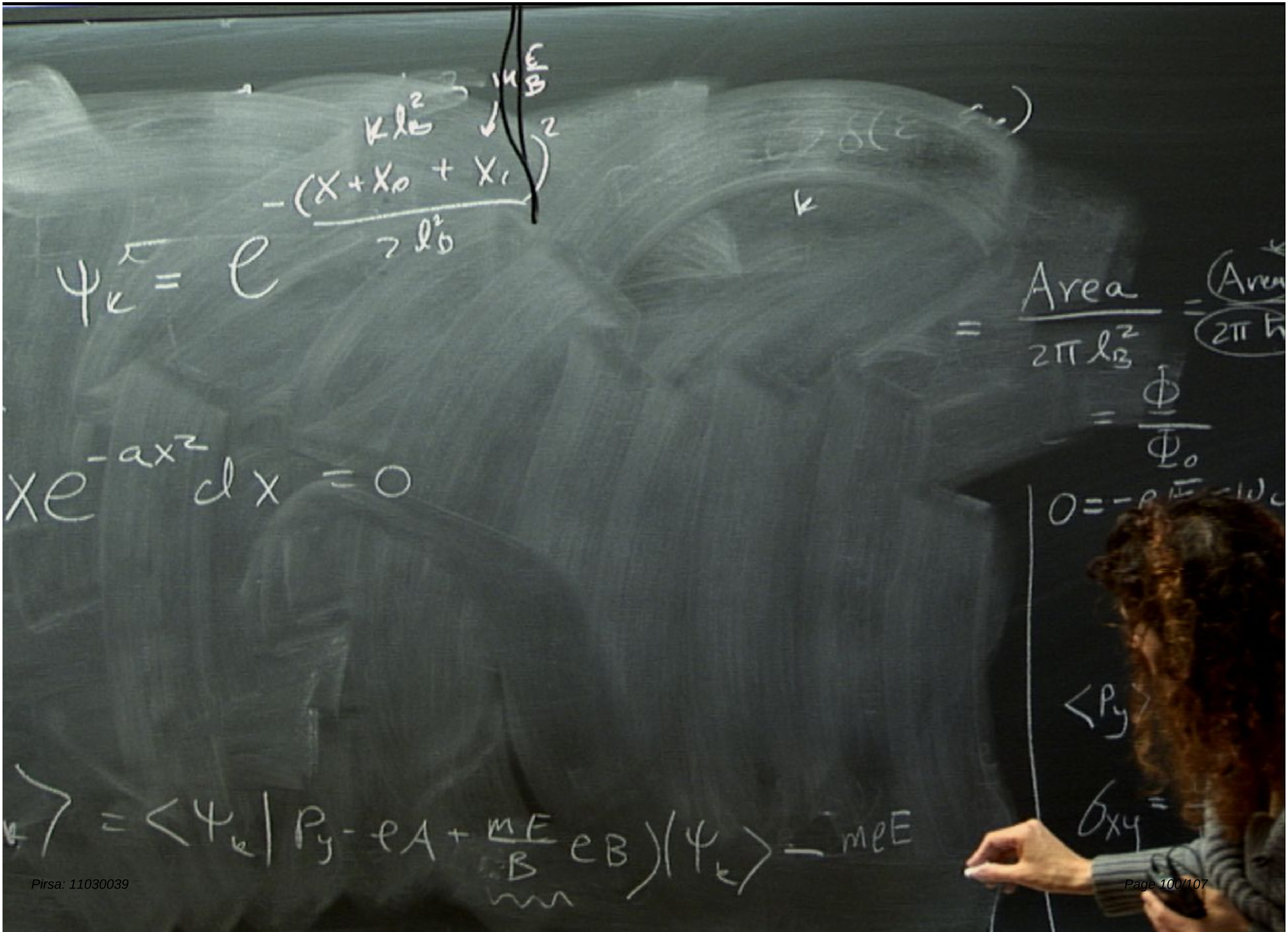
$$= \frac{\Phi}{\Phi_0}$$

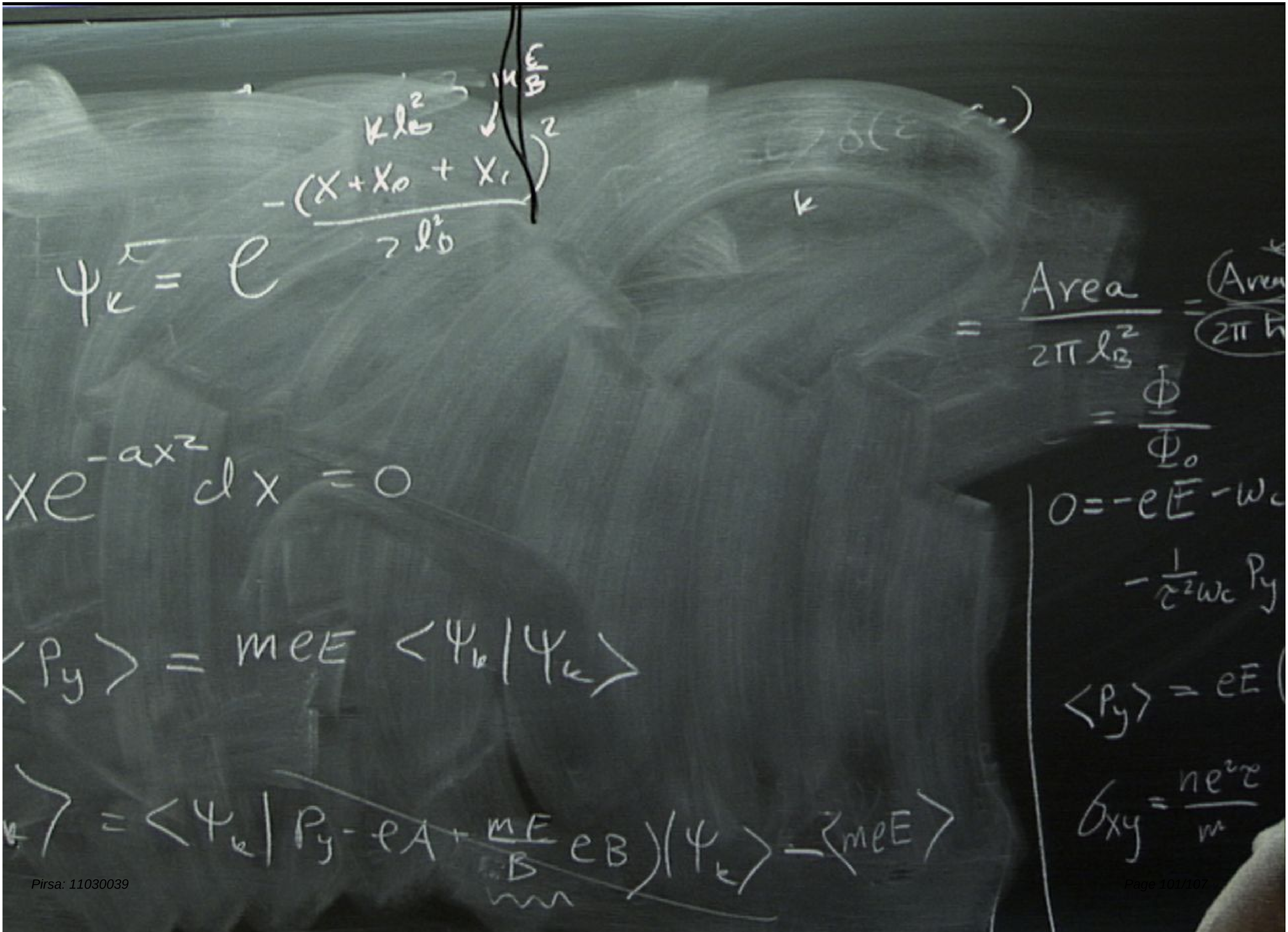
$$0 = -eE - \omega_c$$

$$-\frac{1}{\tau^2 \omega_c} P_y$$

$$\langle P_y \rangle = eE$$

$$\sigma_{xy} = \frac{ne^2\tau}{m}$$


Area



Area
2π l_B^2
Φ
Φ_0
0 = -eE - ω_c
<P_y> = meE <Ψ_k | Ψ_k>
<P_y> = eE
σ_xy = ne^2τ / m

$$\psi_k = e^{-\frac{(X + X_0 + X_1)^2}{2 l_B^2}}$$

$k l_B^2$, $\frac{E}{B}$

$$= \frac{\text{Area}}{2\pi l_B^2} = \frac{(\text{Area})}{(2\pi \hbar}$$

$$= \frac{\Phi}{\Phi_0}$$

$$J_y = \frac{meE}{B} \cdot V$$

$$x e^{-ax^2} dx = 0$$

$$0 = -eE - \omega_c$$

$$-\frac{1}{\tau^2 \omega_c} P_y$$

$$\langle P_y \rangle = \frac{meE}{B} \langle \psi_k | \psi_k \rangle$$

$$\langle P_y \rangle = eE$$

$$\rangle = \langle \psi_k | P_y - eA + \frac{mE}{B} e \;)| \psi_k \rangle - \langle meE \rangle$$

$$\sigma_{xy} = \frac{ne^2\tau}{m}$$

$$\psi_k = e^{-\frac{(X + X_0 + X_1)^2}{2 l_B^2}}$$

$$J_y = \frac{meE}{B} \cdot \nu \frac{e}{m}$$

$$\sigma_{xy} = \nu \frac{e^2}{h}$$

$$= \frac{\text{Area}}{2\pi l_B^2} = \frac{(\text{Area})}{(2\pi\, l_B^2)}$$

$$= \frac{\Phi}{\Phi_0}$$

$$\int x e^{-ax^2} dx = 0$$

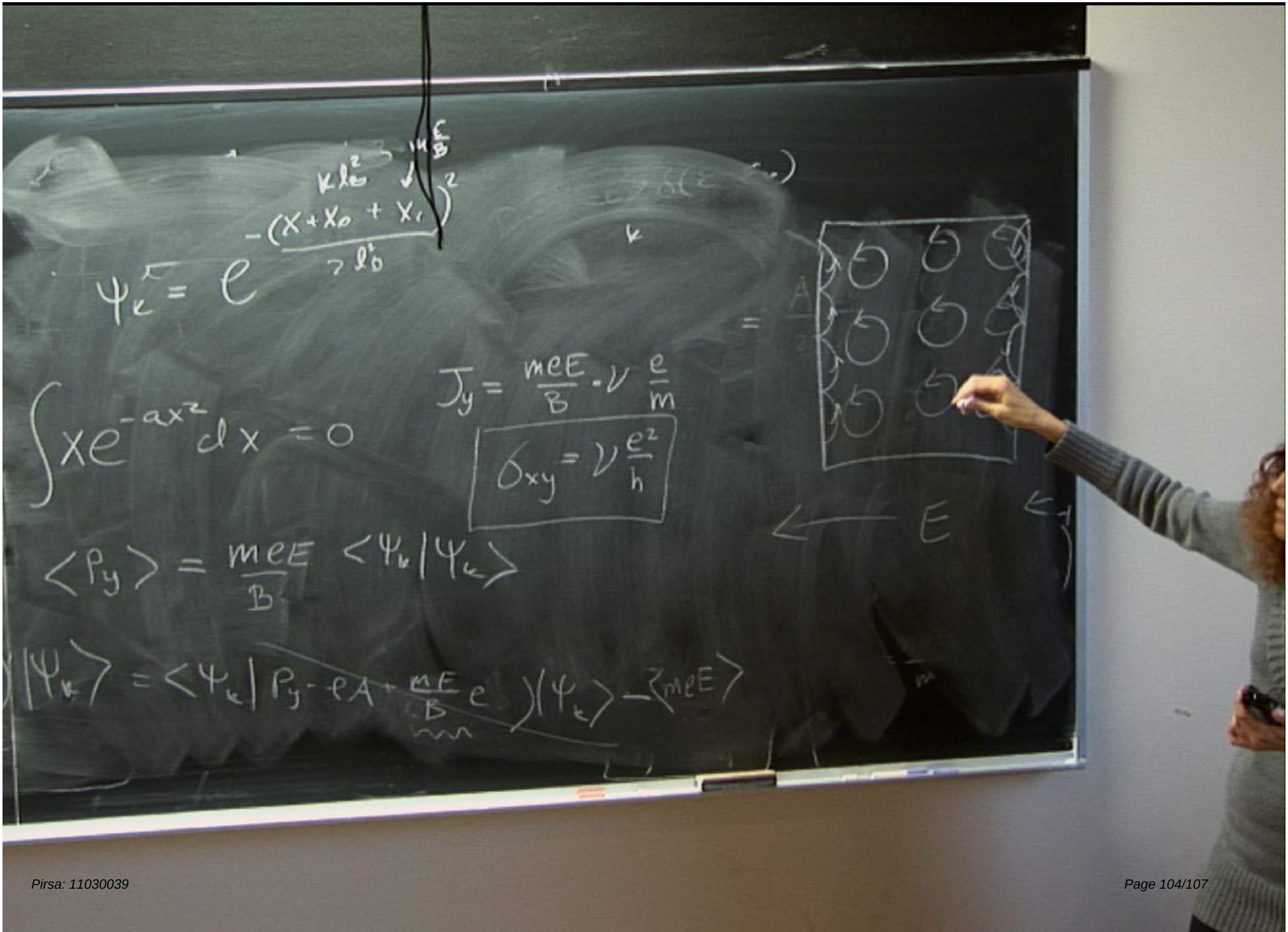
$$\langle P_y \rangle = \frac{meE}{B} \langle \psi_k | \psi_k \rangle$$

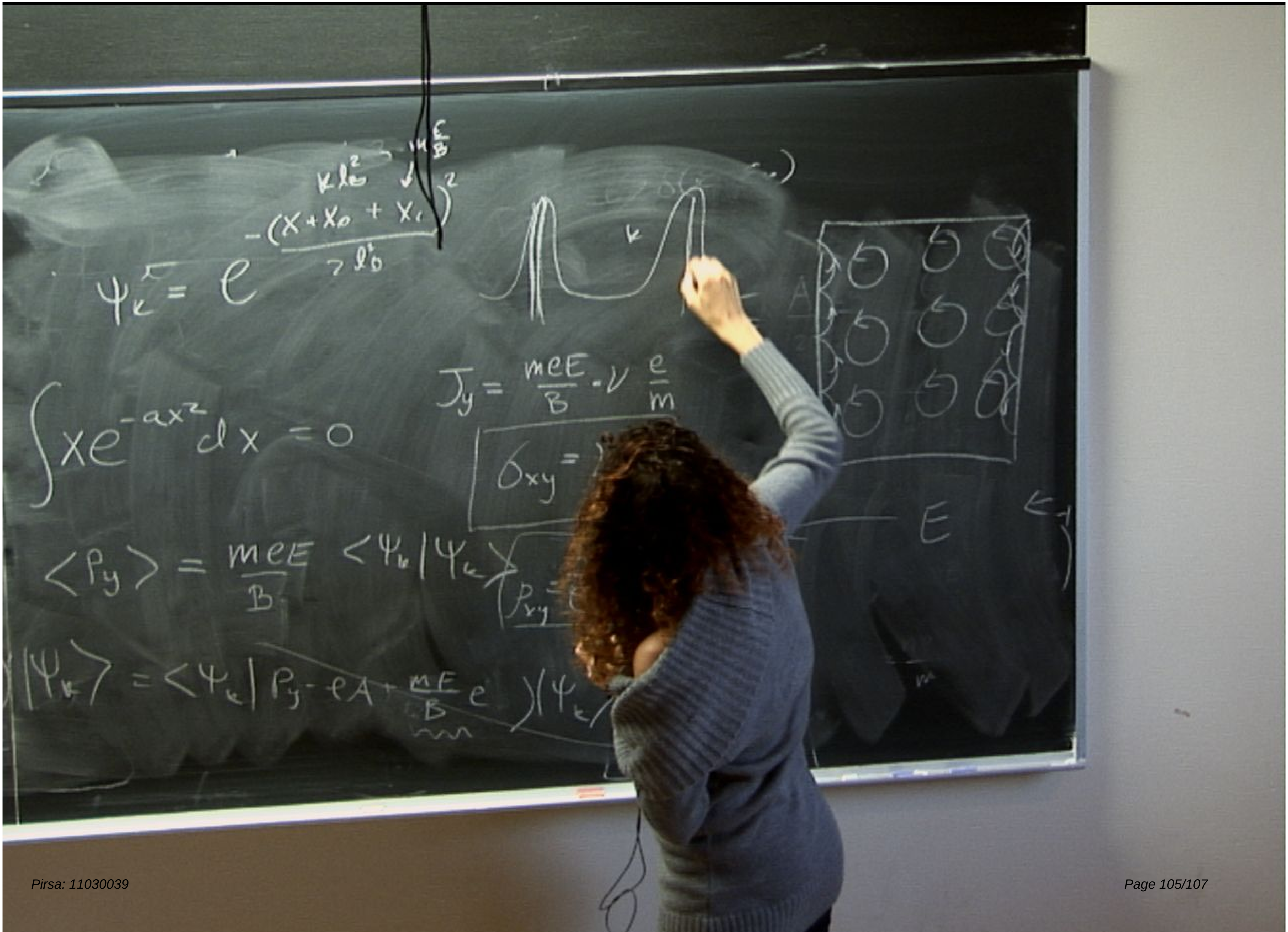
$$0 = -eE - \omega_c \ldots - \frac{1}{\tau^2 \omega_c} P_y$$

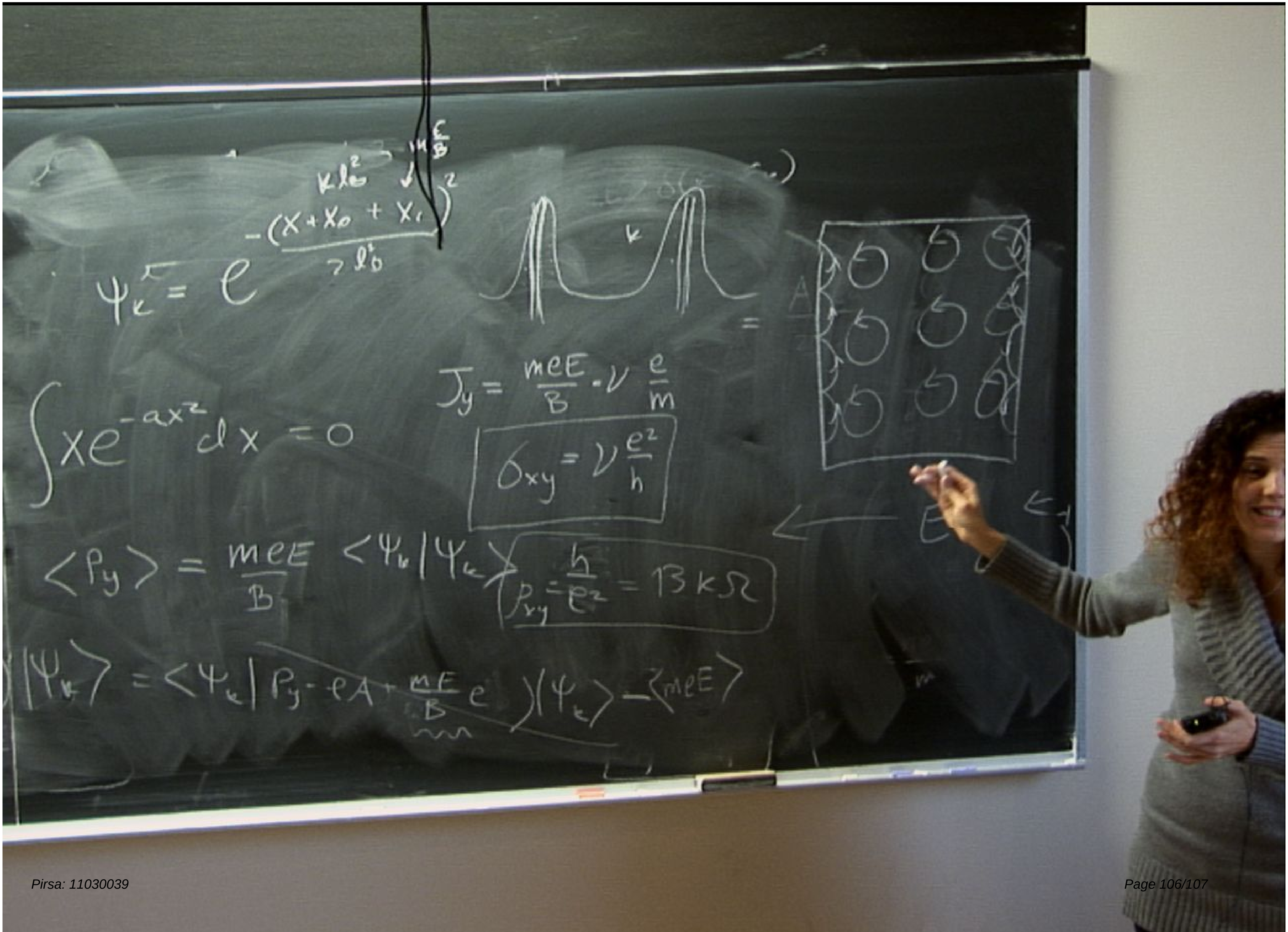
$$\langle P_y \rangle = eE \ldots$$

$$\sigma_{xy} = \frac{ne^2\tau}{m}$$

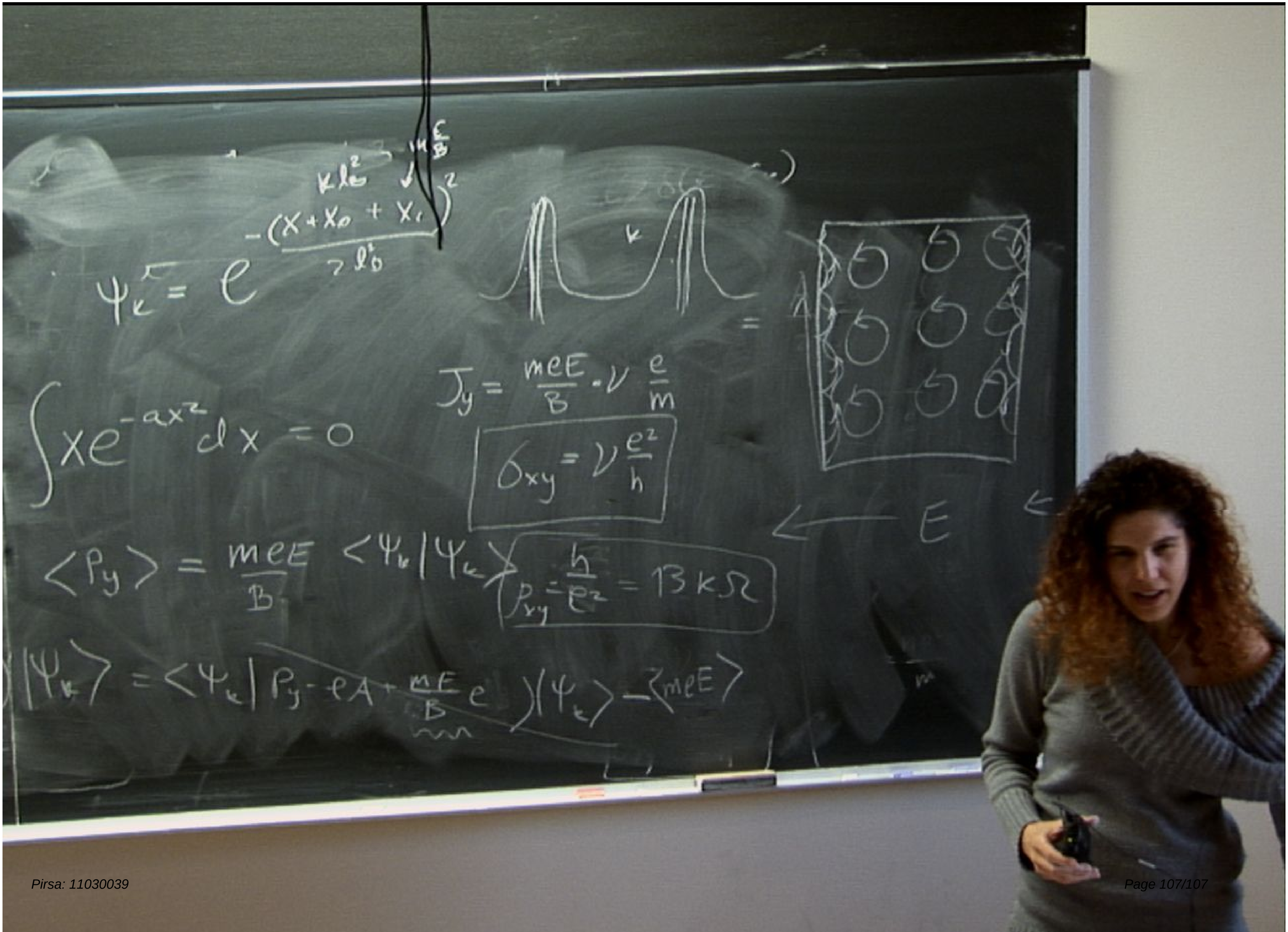
$$\langle P_y \rangle = \langle \psi_k | P_y - eA + \frac{mE}{B} e \ldots | \psi_k \rangle = \langle meE \rangle$$


Jy = meE/B · ν e/m
σxy = ν e²/h
∫xe^{-ax²} dx = 0
<Py> = meE/B <Ψk|Ψk>
E





∫xe^(-ax²) dx = 0
Jy = meE/B · ν e/m
σxy = ν e²/h
ρxy = h/e² = 13 kΩ


Jy = meE/B · ν e/m
σxy = ν e²/h
∫xe^{-ax²} dx = 0
<Py> = meE/B <ψk|ψk>
ρxy = h/e² = 13 kΩ
E