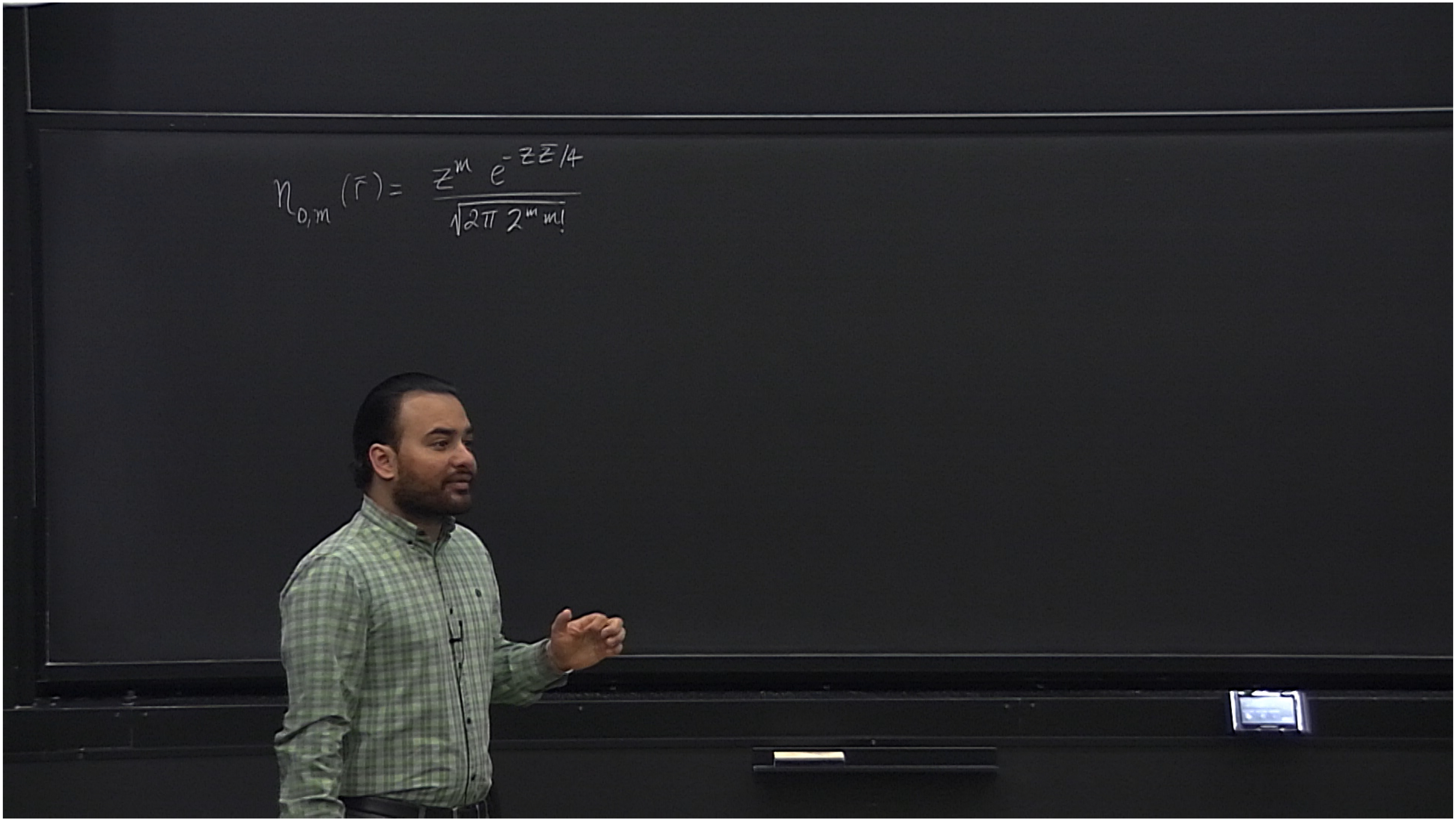
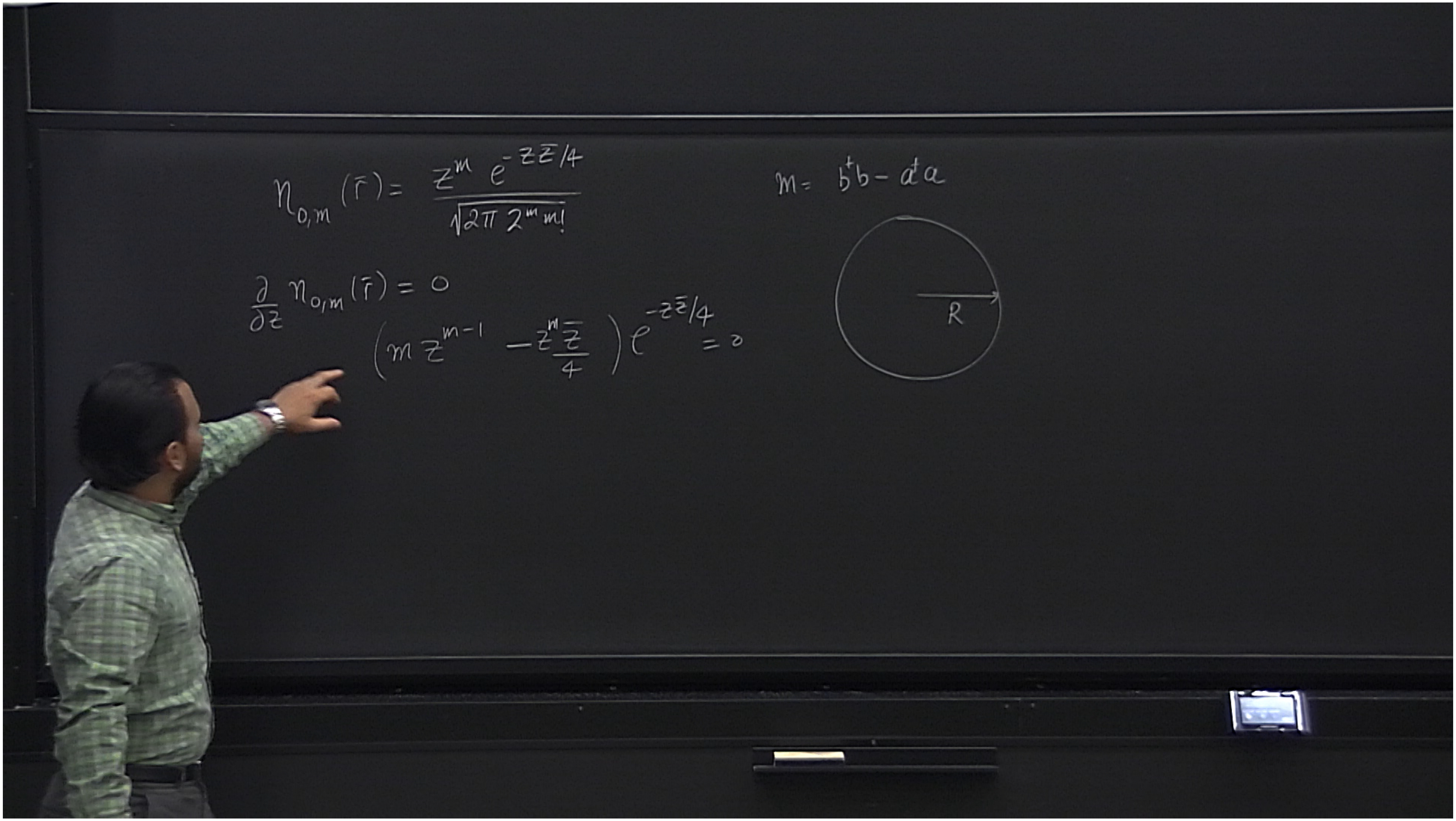
Title: PSI 17/18 - Condensed Matter - Lecture 14

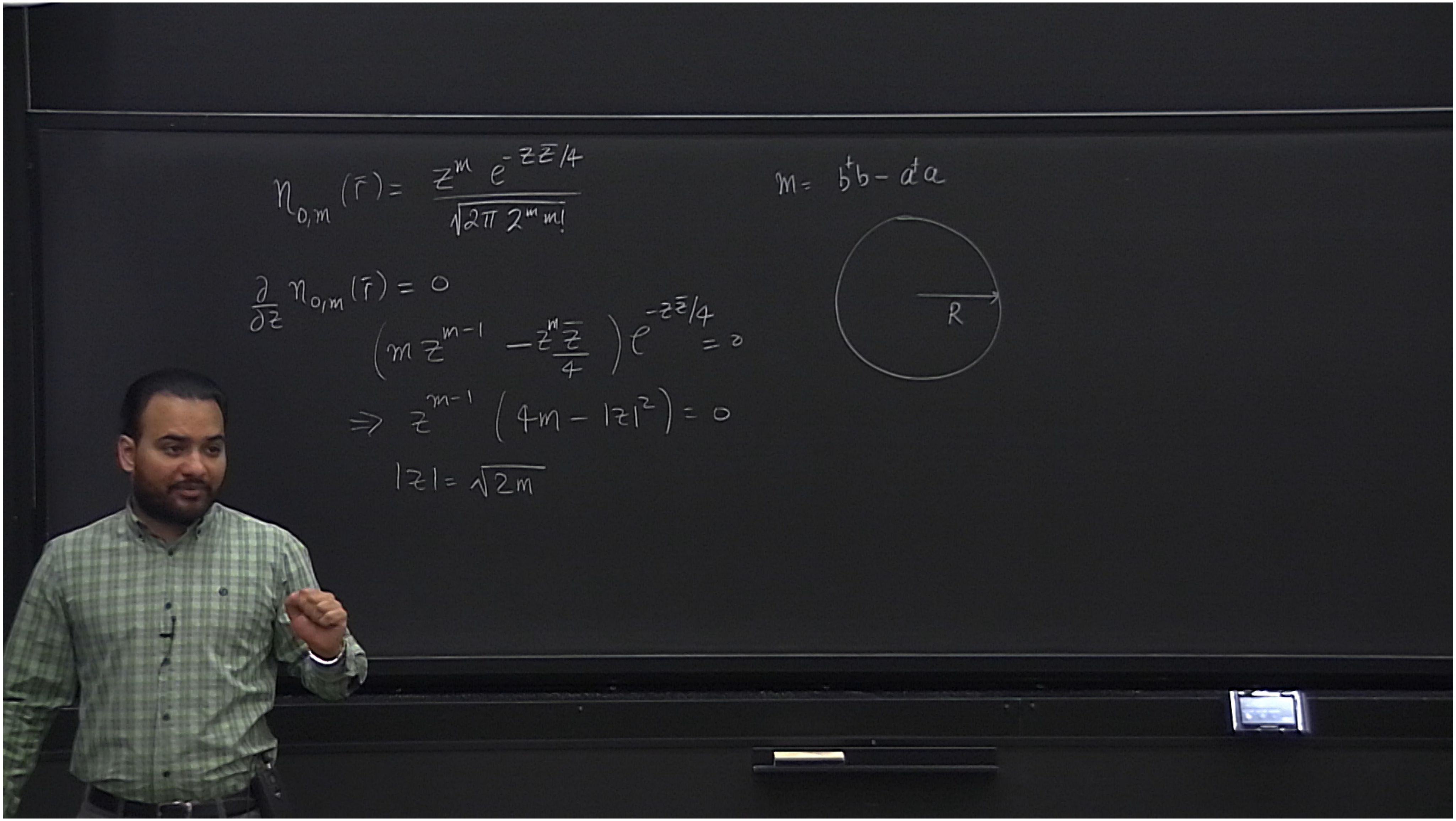
Date: Nov 23, 2017 10:45 AM

URL: http://pirsa.org/17110039

Abstract:


$\eta_{0,m}(\bar{r}) = \frac{z^m e^{-z\bar{z}/4}}{\sqrt{2\pi\, 2^m m!}}$


$\eta_{0,m}(\bar{r}) = \frac{z^m e^{-z\bar{z}/4}}{\sqrt{2\pi 2^m m!}}$
$m = b^\dagger b - a^\dagger a$
$\frac{\partial}{\partial z}\eta_{0,m}(\bar{r}) = 0$
$\left(m z^{m-1} - \frac{z^m \bar{z}}{4}\right) e^{-z\bar{z}/4} = 0$
R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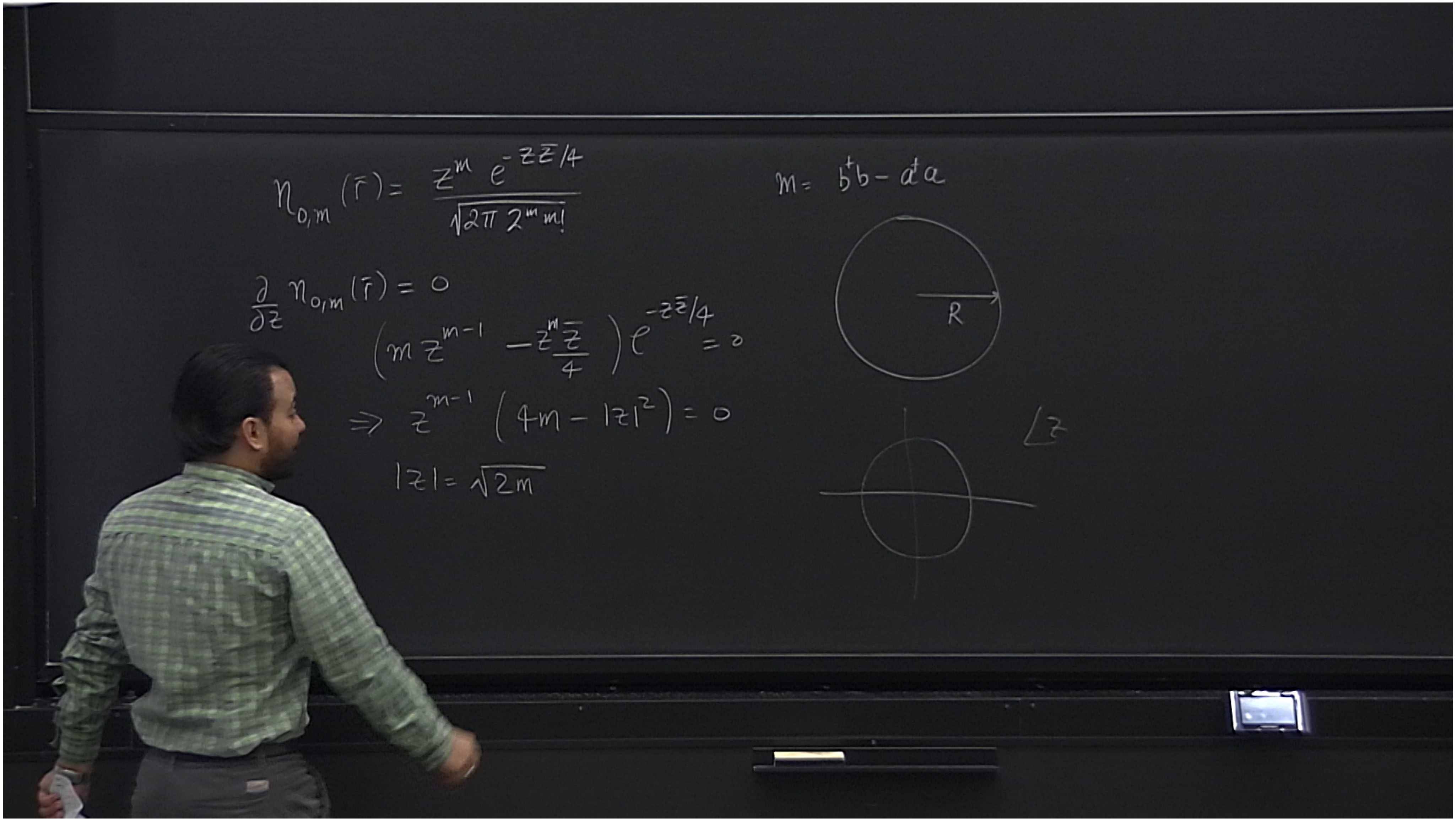
$\left(m z^{m-1} - z^m \frac{\bar{z}}{4}\right) e^{-z\bar{z}/4} = 0$
$\Rightarrow z^{m-1} \left(4m - |z|^2\right) = 0$
$|z| = \sqrt{2m}$
R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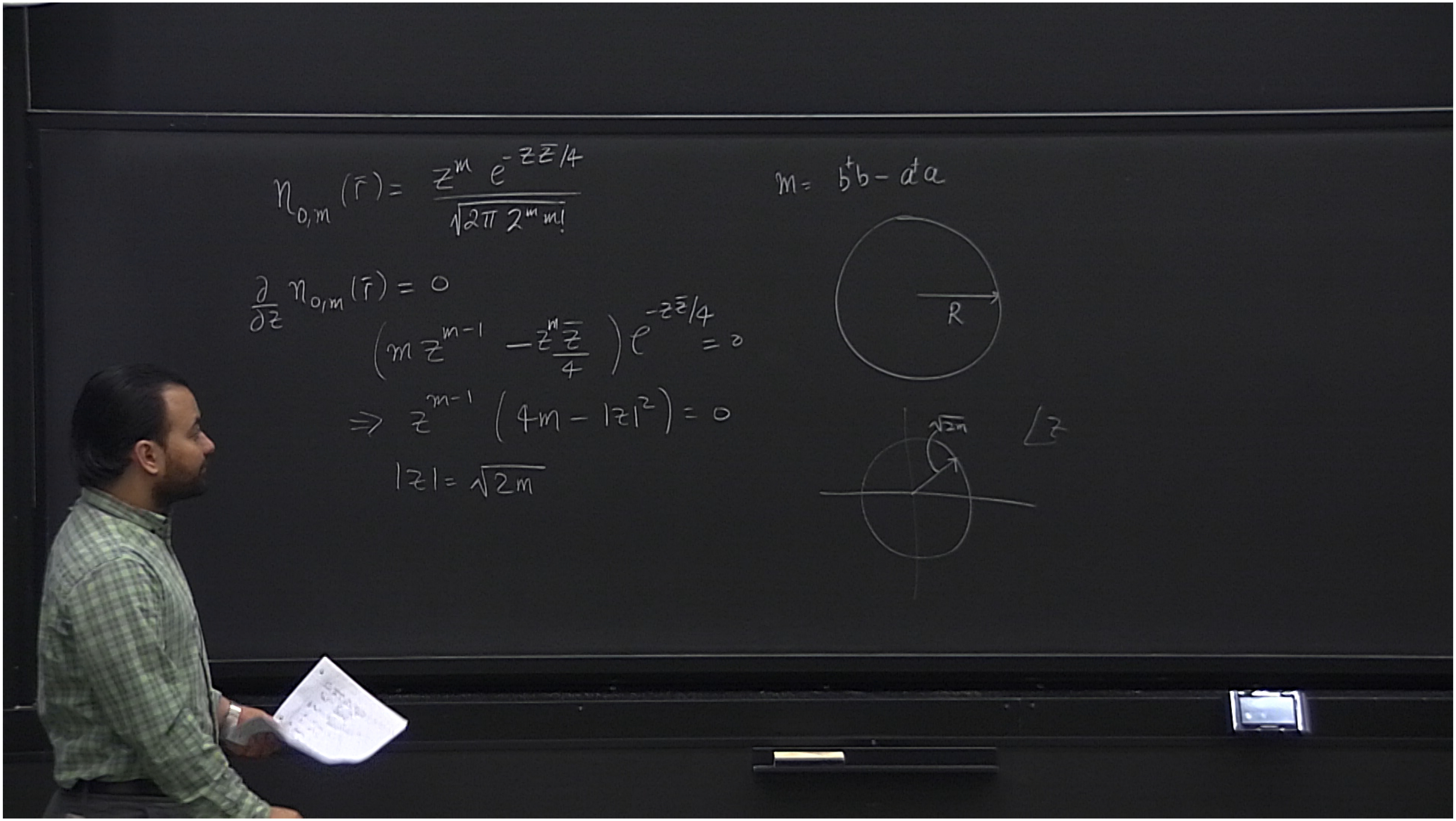
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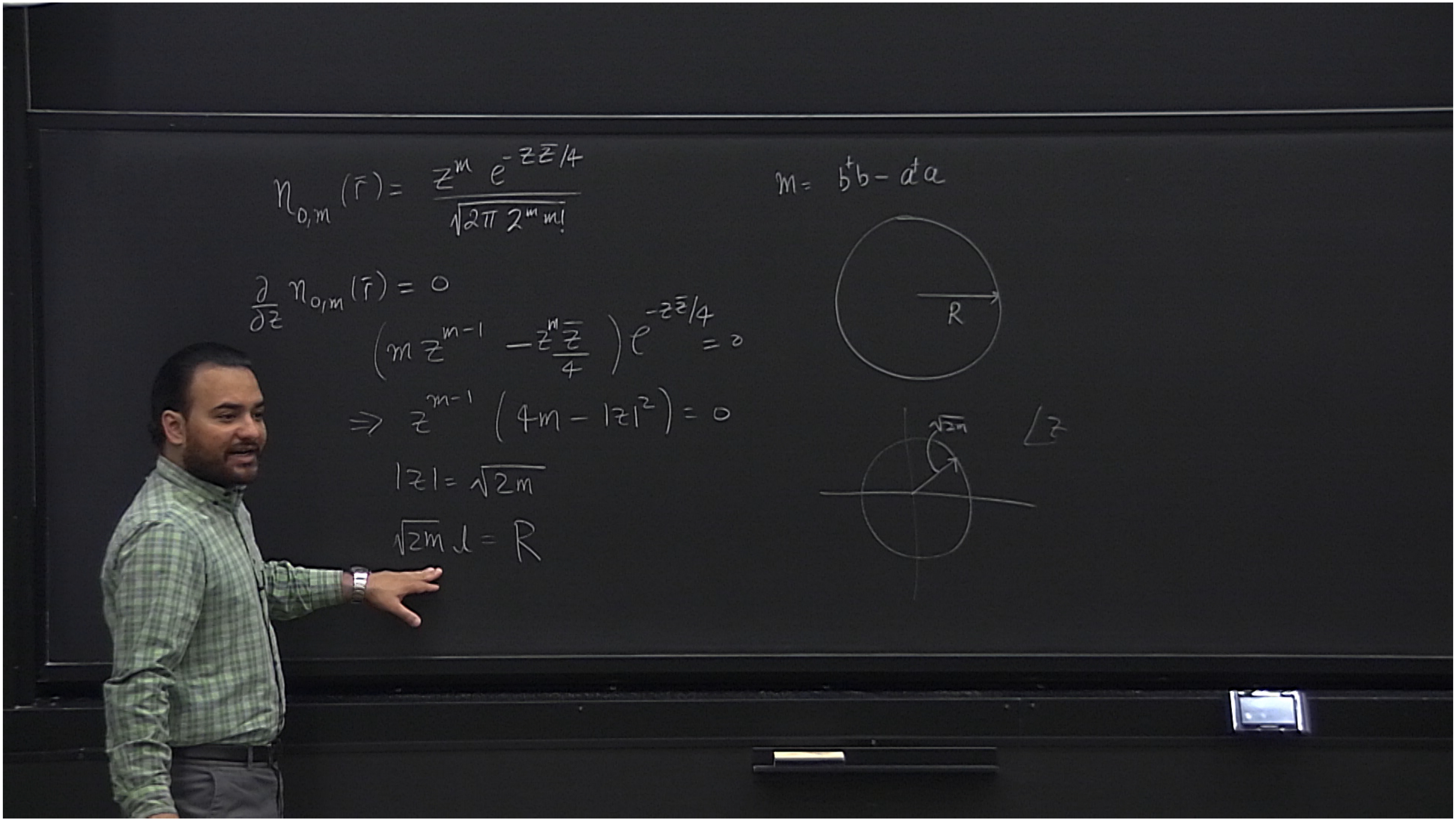

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R
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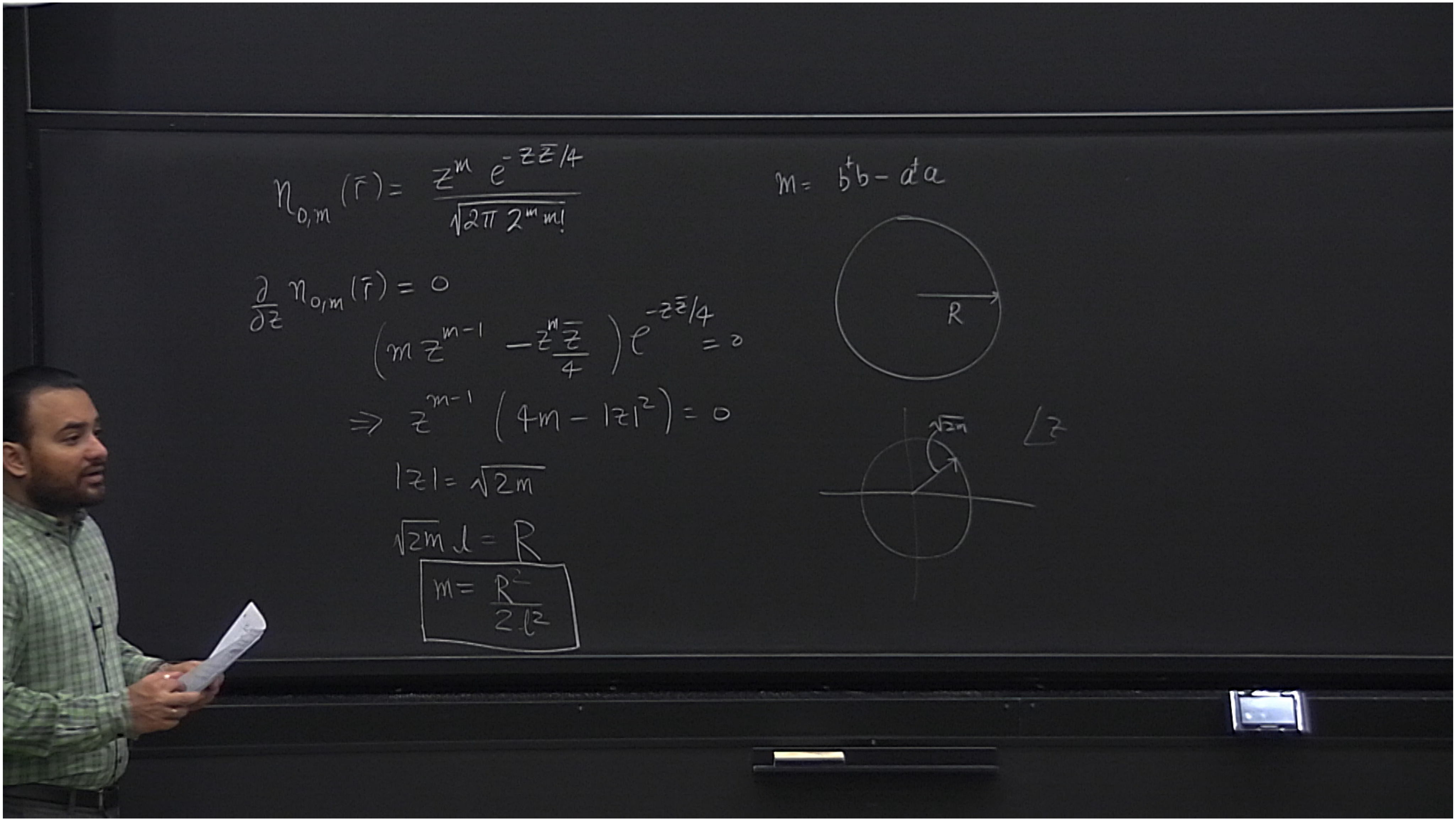

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R
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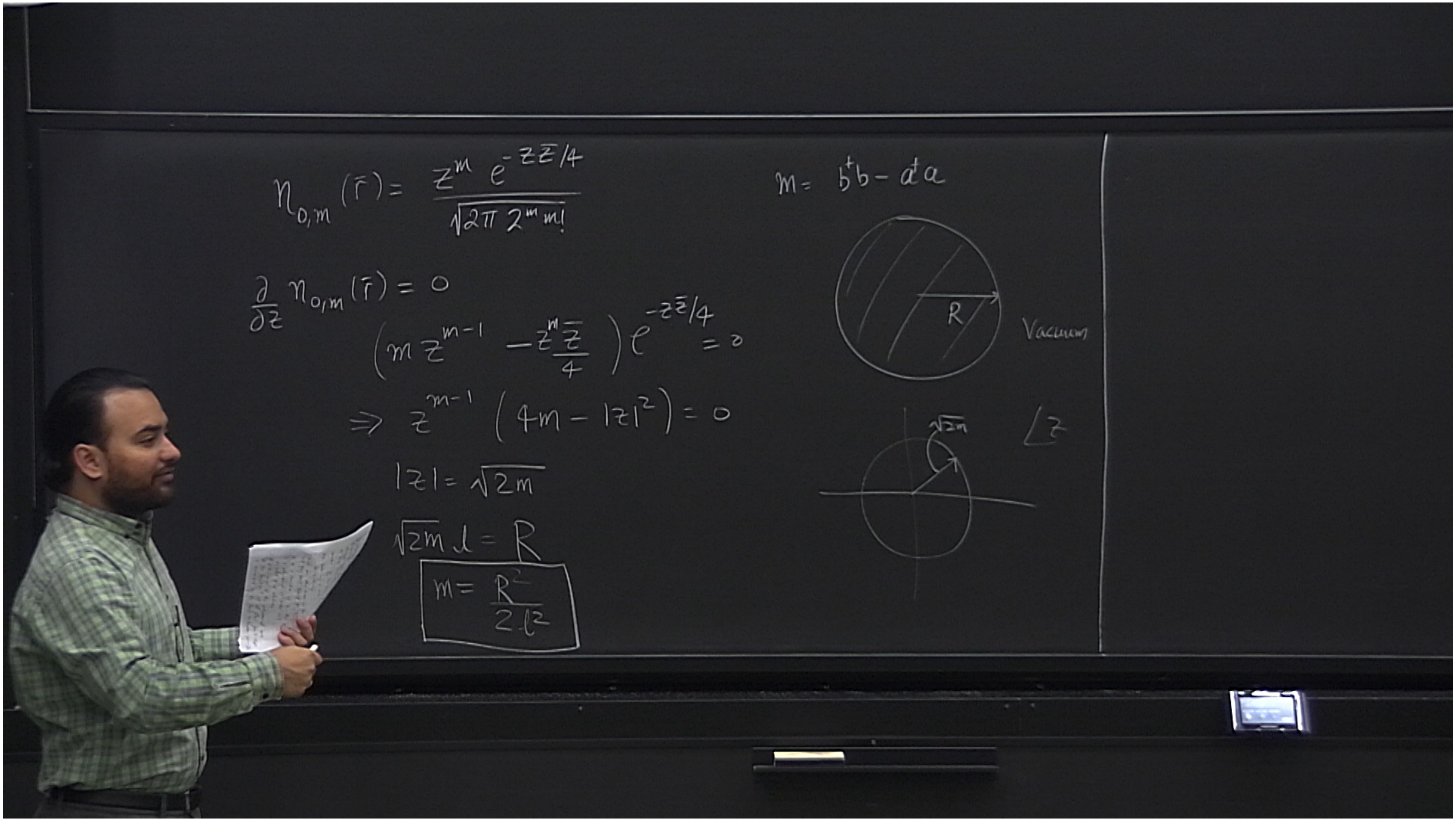
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R
Vacuum
$\sqrt{2m}$
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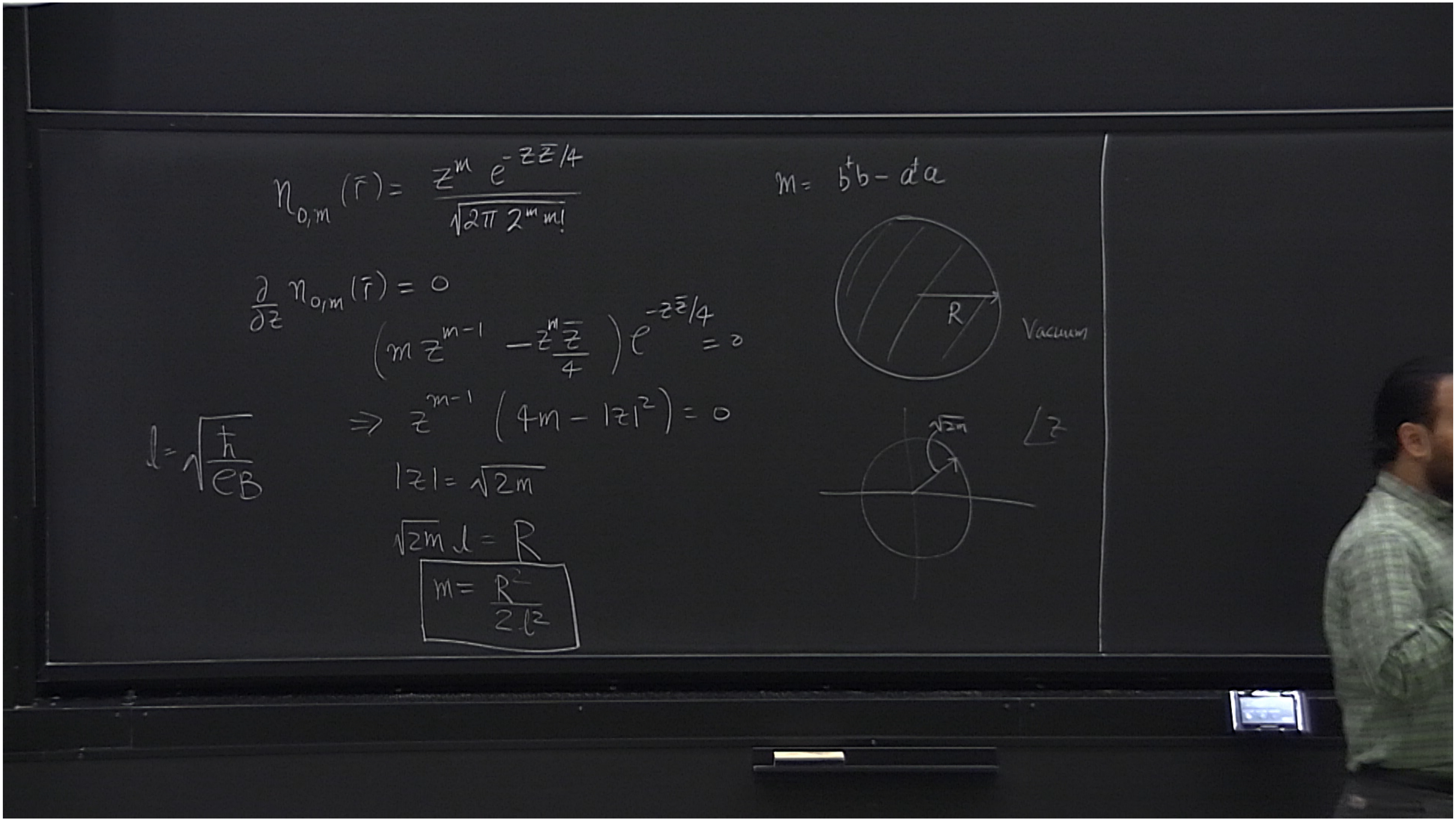
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$l = \sqrt{\frac{\hbar}{eB}}$
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$\sqrt{2m}\, l = R$
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R
Vacuum
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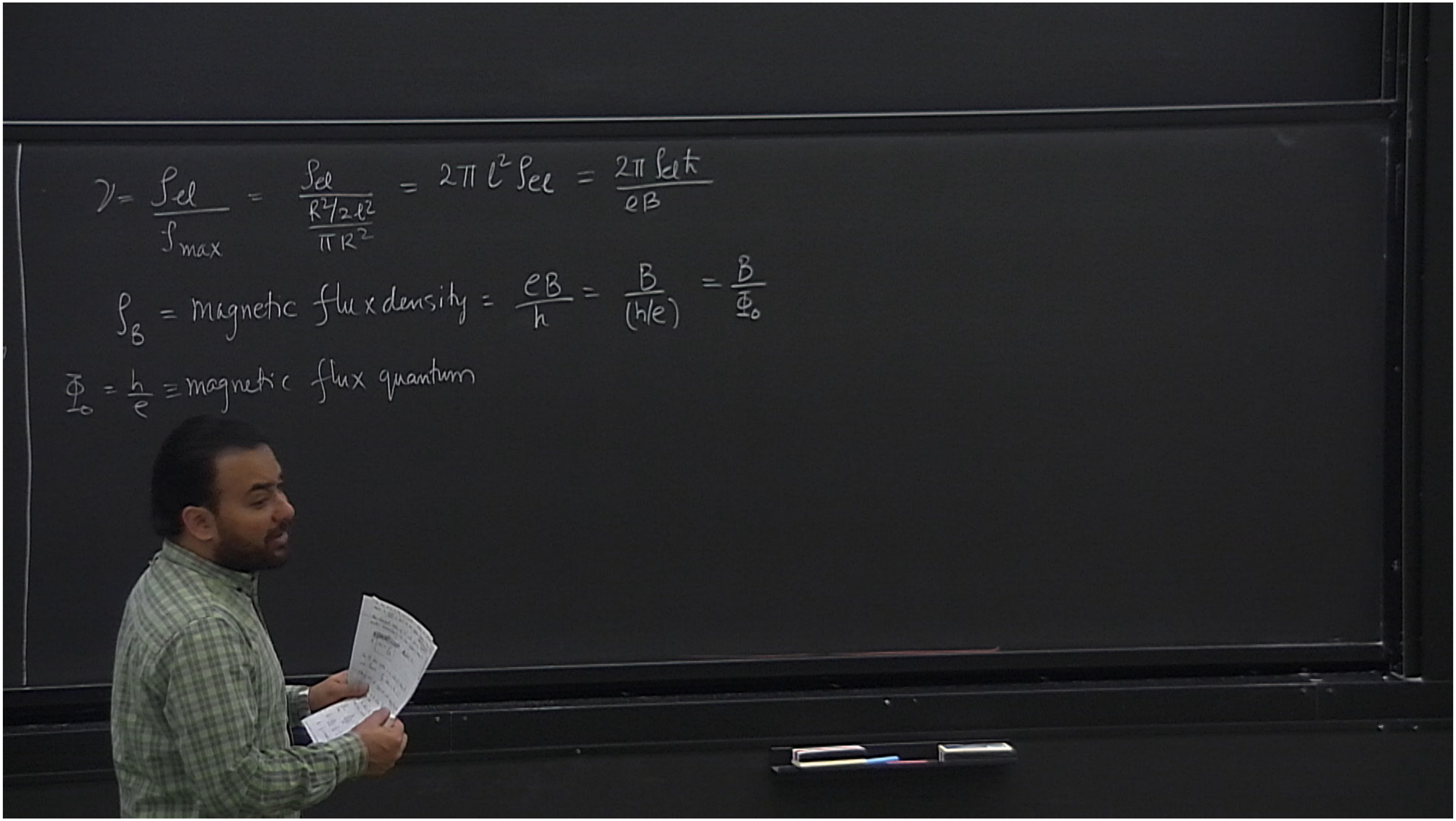
$\nu = \frac{\rho_{el}}{\rho_{max}} = \frac{\rho_{el}}{\frac{R^2/2l^2}{\pi R^2}} = 2\pi l^2 \rho_{el} = \frac{2\pi \rho_{el} \hbar}{eB}$
ρ_B = magnetic flux density = $\frac{eB}{h} = \frac{B}{(h/e)} = \frac{B}{\Phi_0}$
$\Phi_0 = \frac{h}{e}$ = magnetic flux quantum

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$\nu = 1 \Rightarrow$ one electron per magnetic flux quantum

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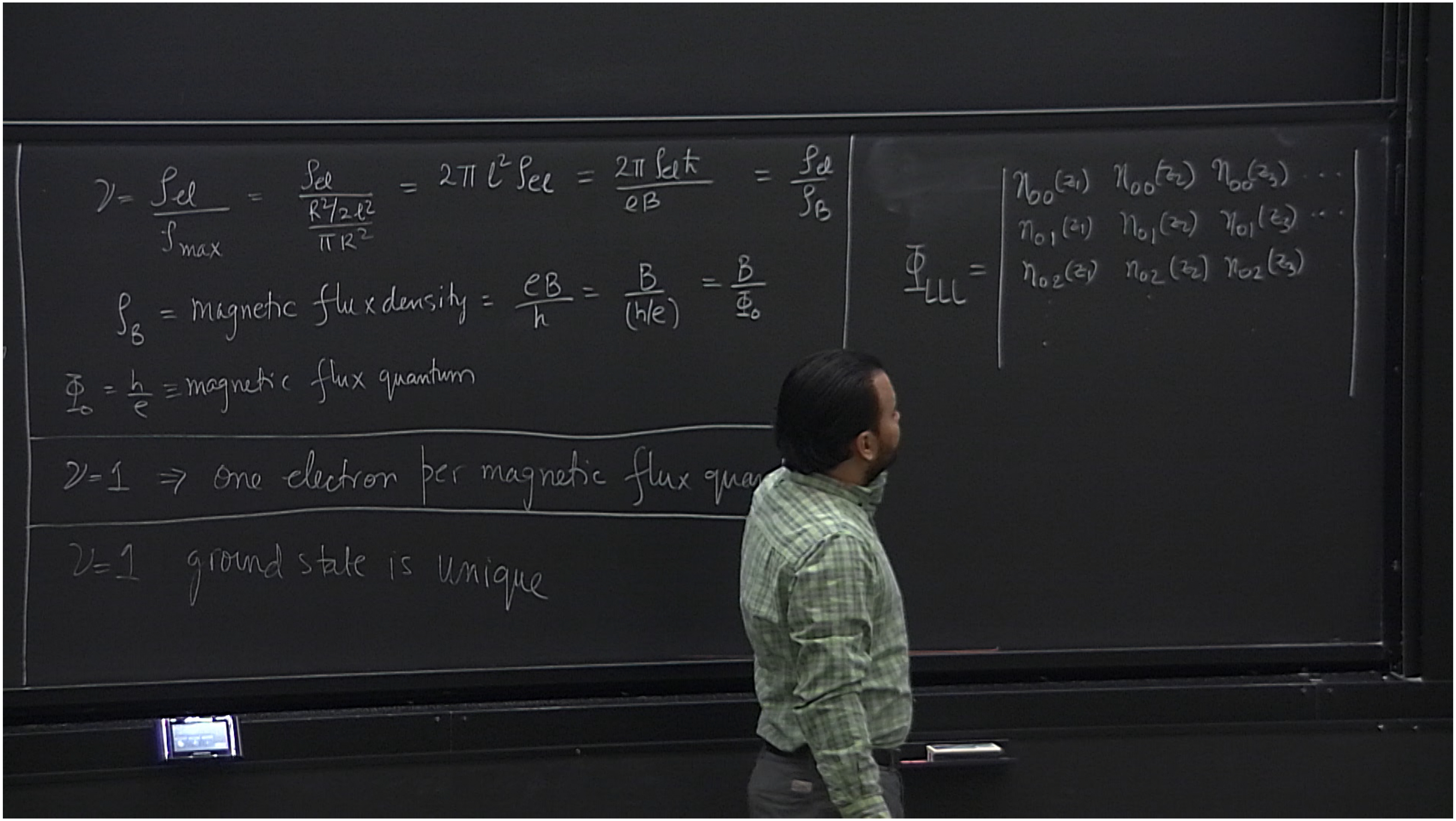
$\nu = 1$ ground state is unique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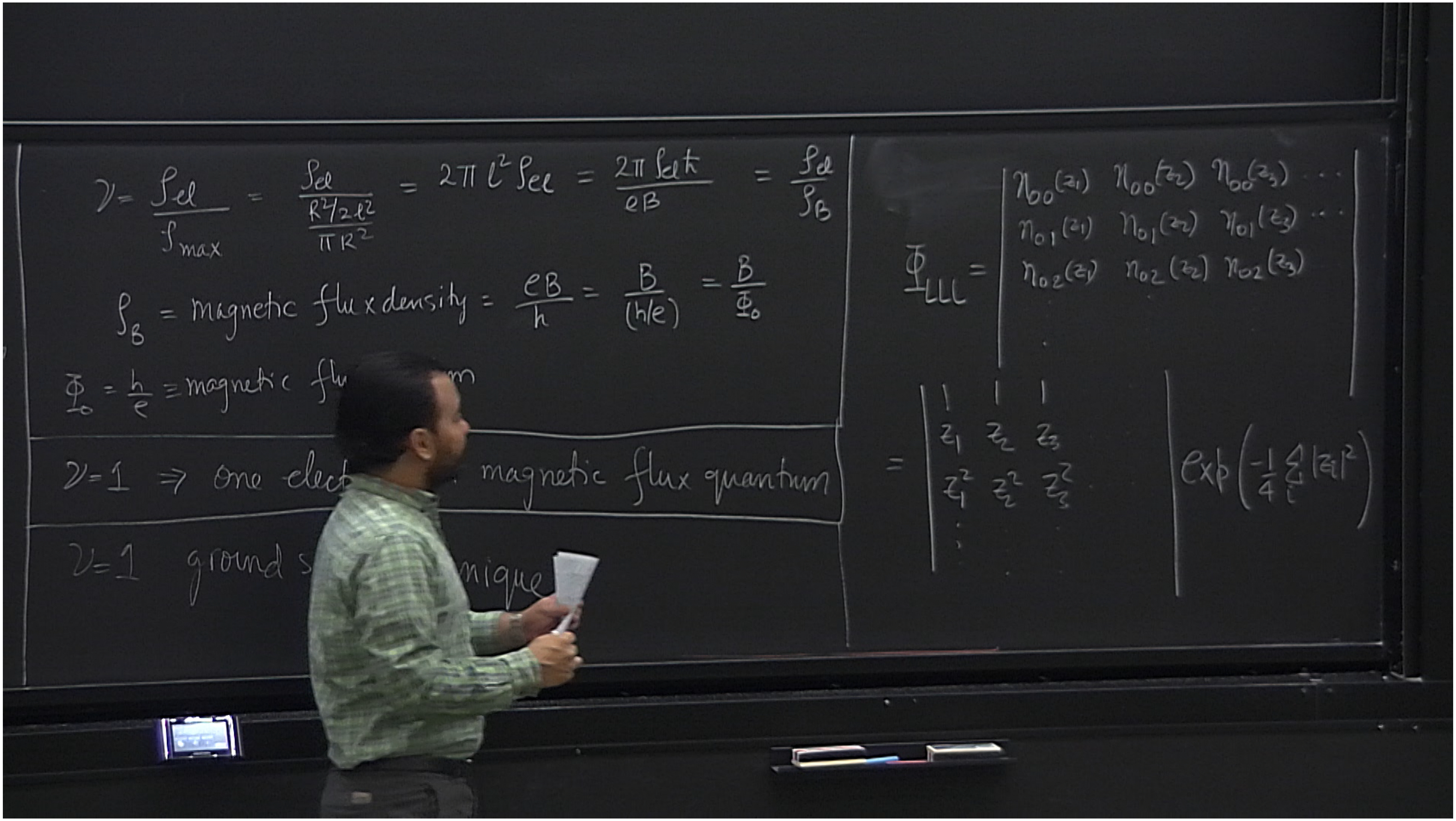
$\Phi_{LLL} = \begin{vmatrix} \eta_{00}(z_1) & \eta_{00}(z_2) & \eta_{00}(z_3) & \cdots \\ \eta_{01}(z_1) & \eta_{01}(z_2) & \eta_{01}(z_3) & \cdots \\ \eta_{02}(z_1) & \eta_{02}(z_2) & \eta_{02}(z_3) & \\ \vdots & & & \end{vmatrix}$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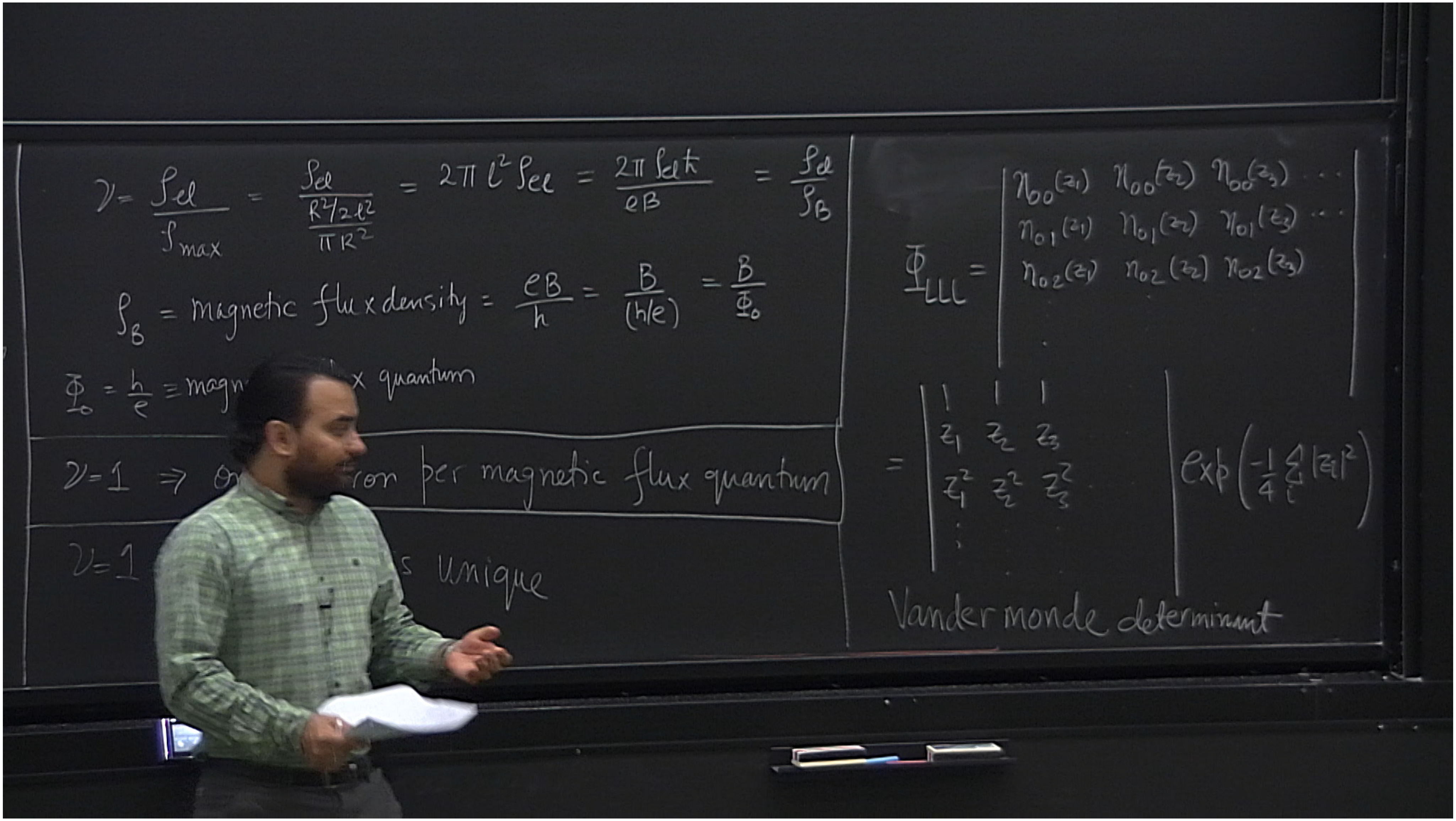
$= \begin{vmatrix} 1 & 1 & 1 \\ z_1 & z_2 & z_3 \\ z_1^2 & z_2^2 & z_3^2 \\ \vdots & & \end{vmatrix} \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$



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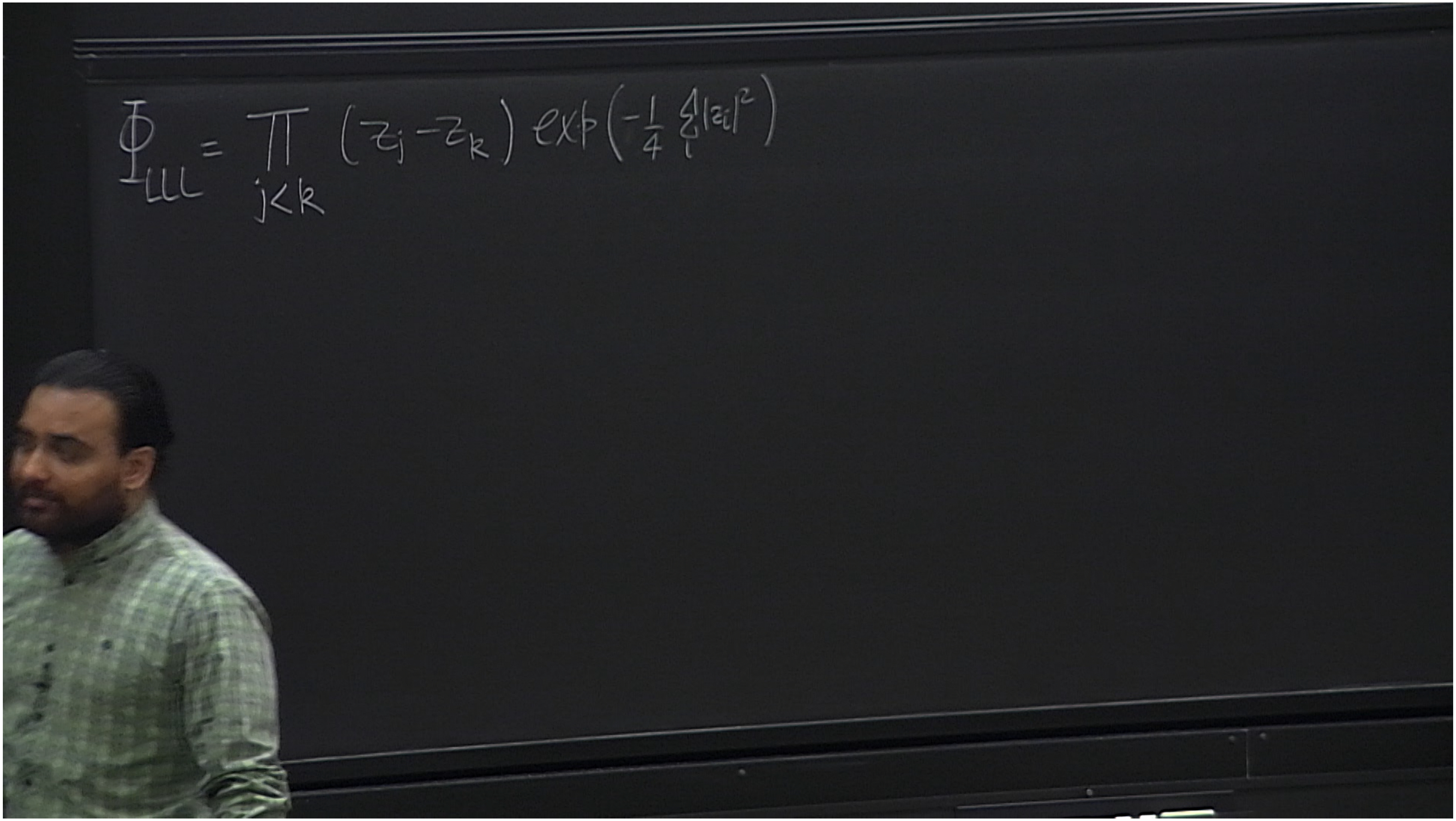
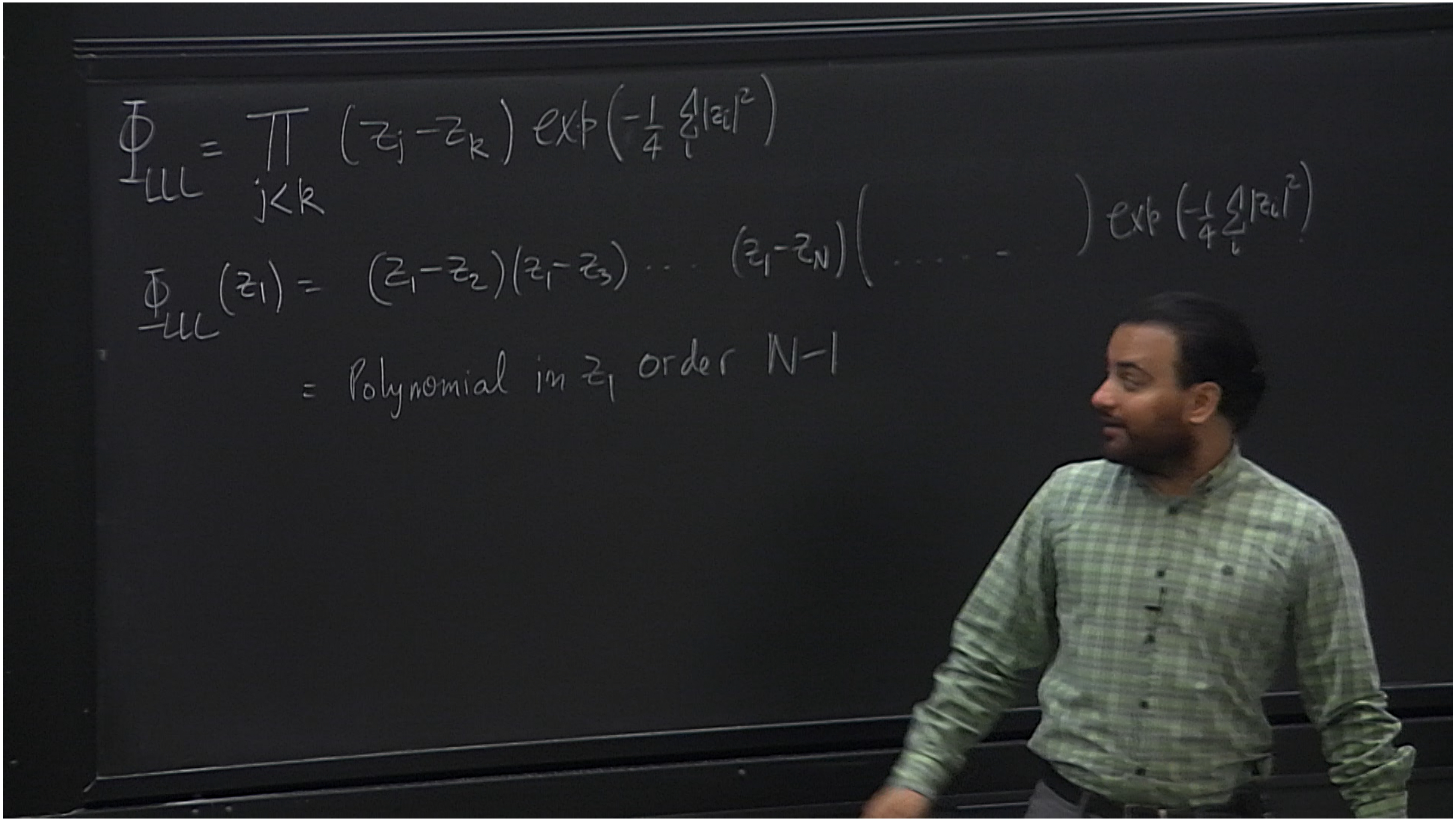
Vandermonde determinant



$$\Phi_{LLL} = \prod_{j<k} (z_j - z_k) \exp\left(-\frac{1}{4} \sum_i |z_i|^2\right)$$


$\Phi_{LLL} = \prod_{j<k} (z_j - z_k) \exp\left(-\frac{1}{4} \sum_i |z_i|^2\right)$
$\Phi_{LLL}(z_1) = (z_1 - z_2)(z_1 - z_3) \ldots (z_1 - z_N)(\ldots\ldots) \exp\left(-\frac{1}{4} \sum_i |z_i|^2\right)$
= Polynomial in z_1 order $N-1$

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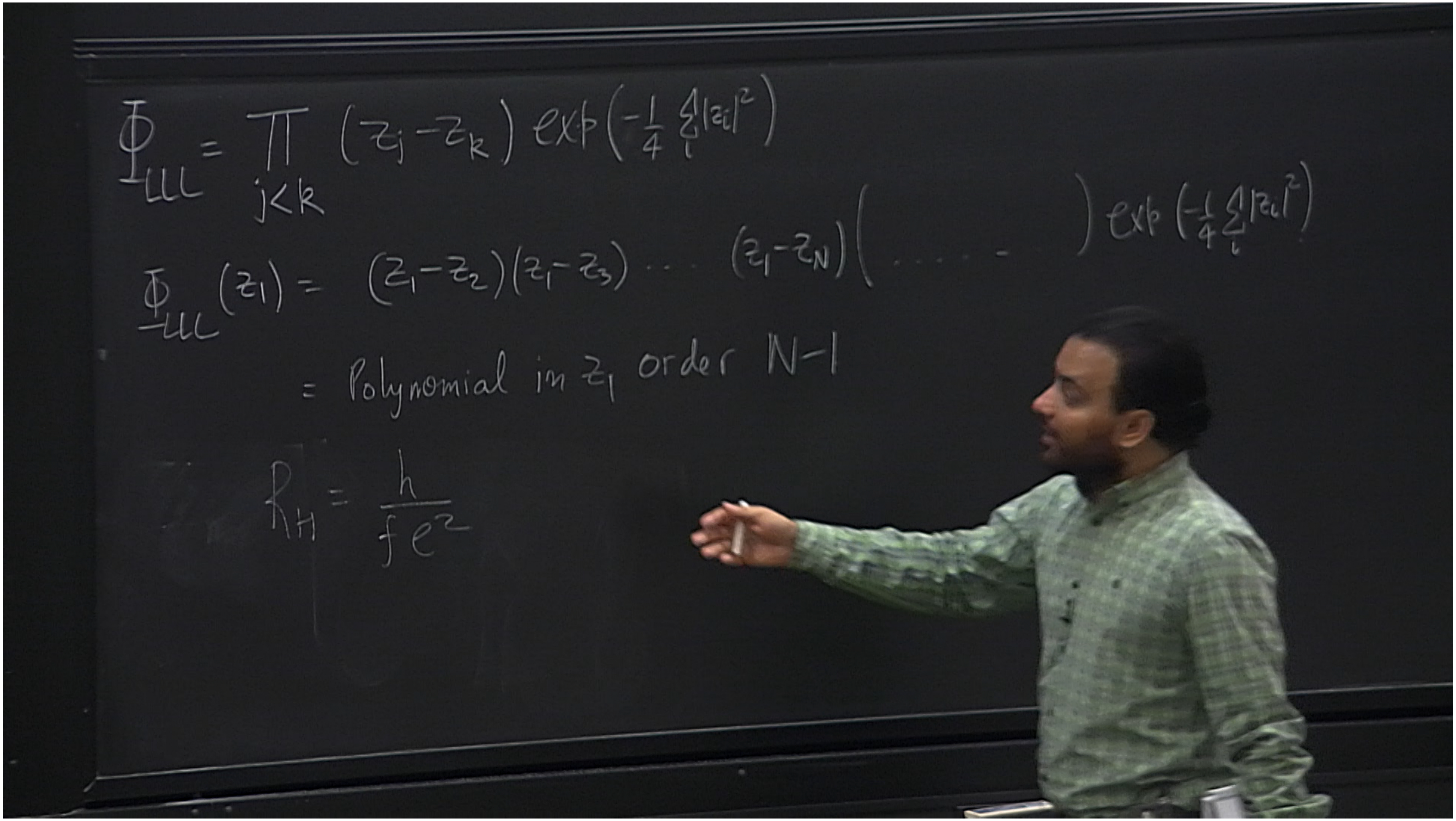
$$= \text{Polynomial in } z_1 \text{ order } N-1$$

$$\Phi_{n=2} =$$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$R_H = \frac{h}{f e^2}$

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$=$ Polynomial in z_1 order $N-1$

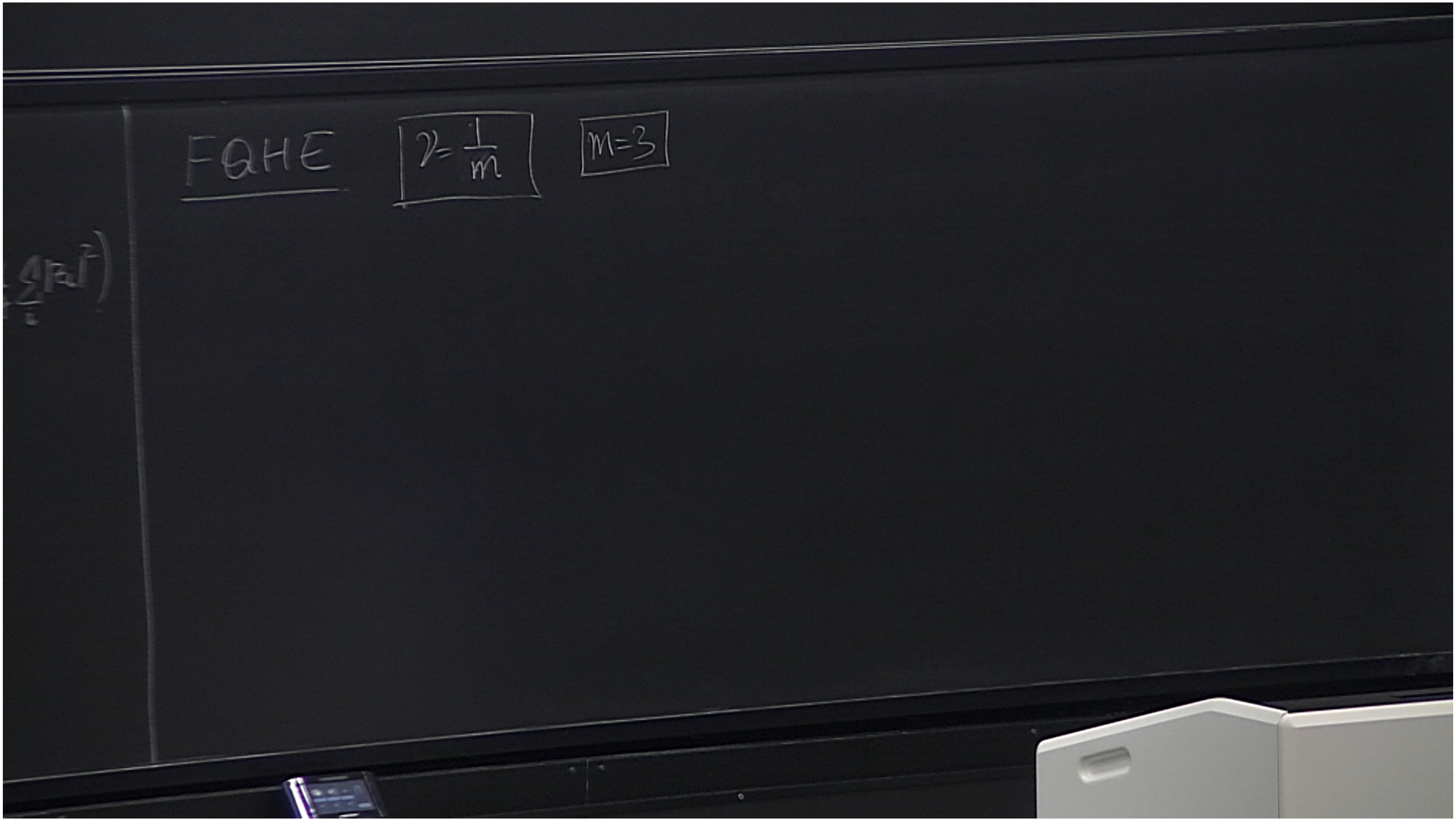
$$R_H = \frac{h}{f e^2} \qquad f = \nu$$

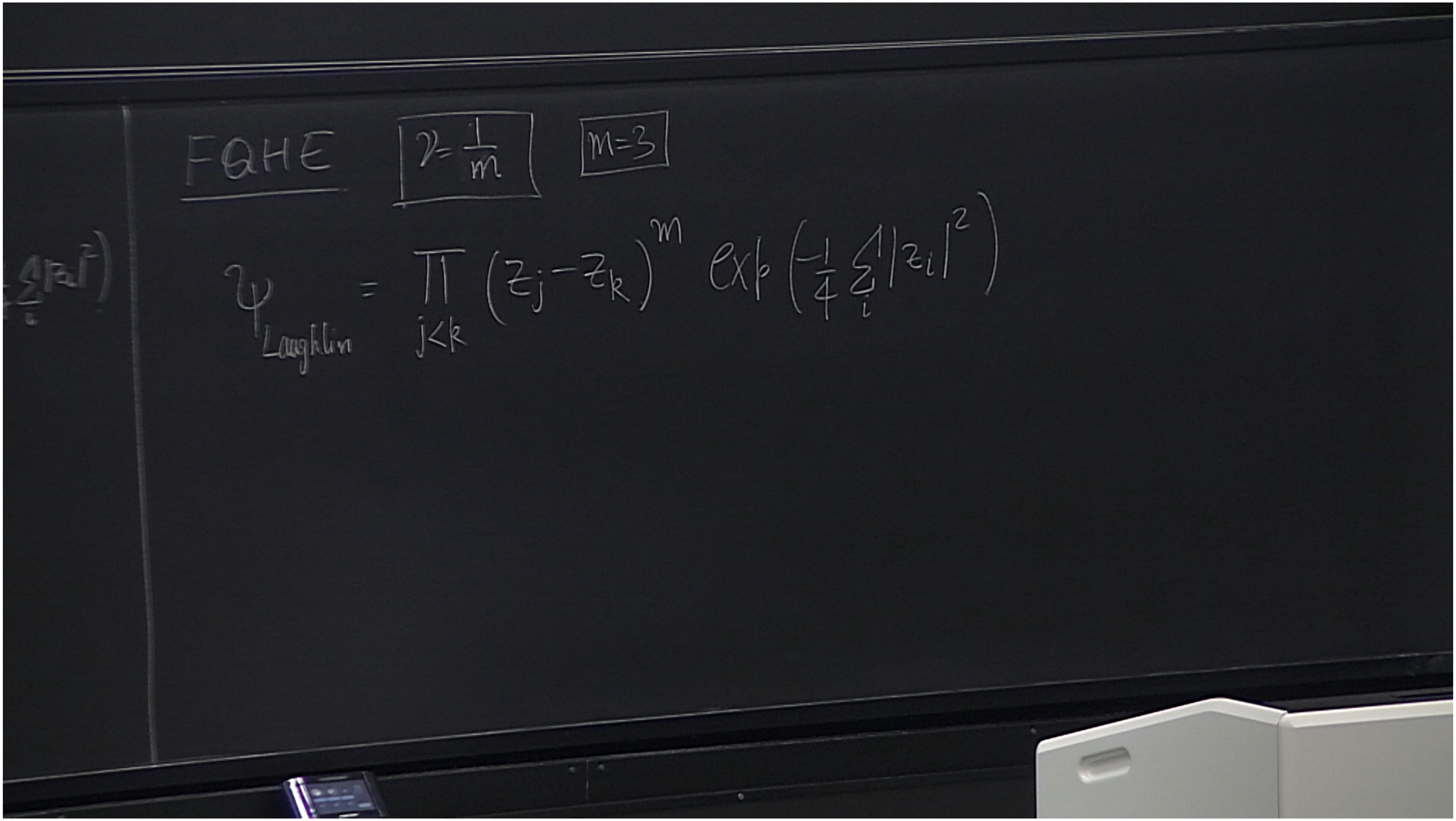
$$\Phi_{LLL} = \prod_{j<k} (z_j - z_k) \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$$

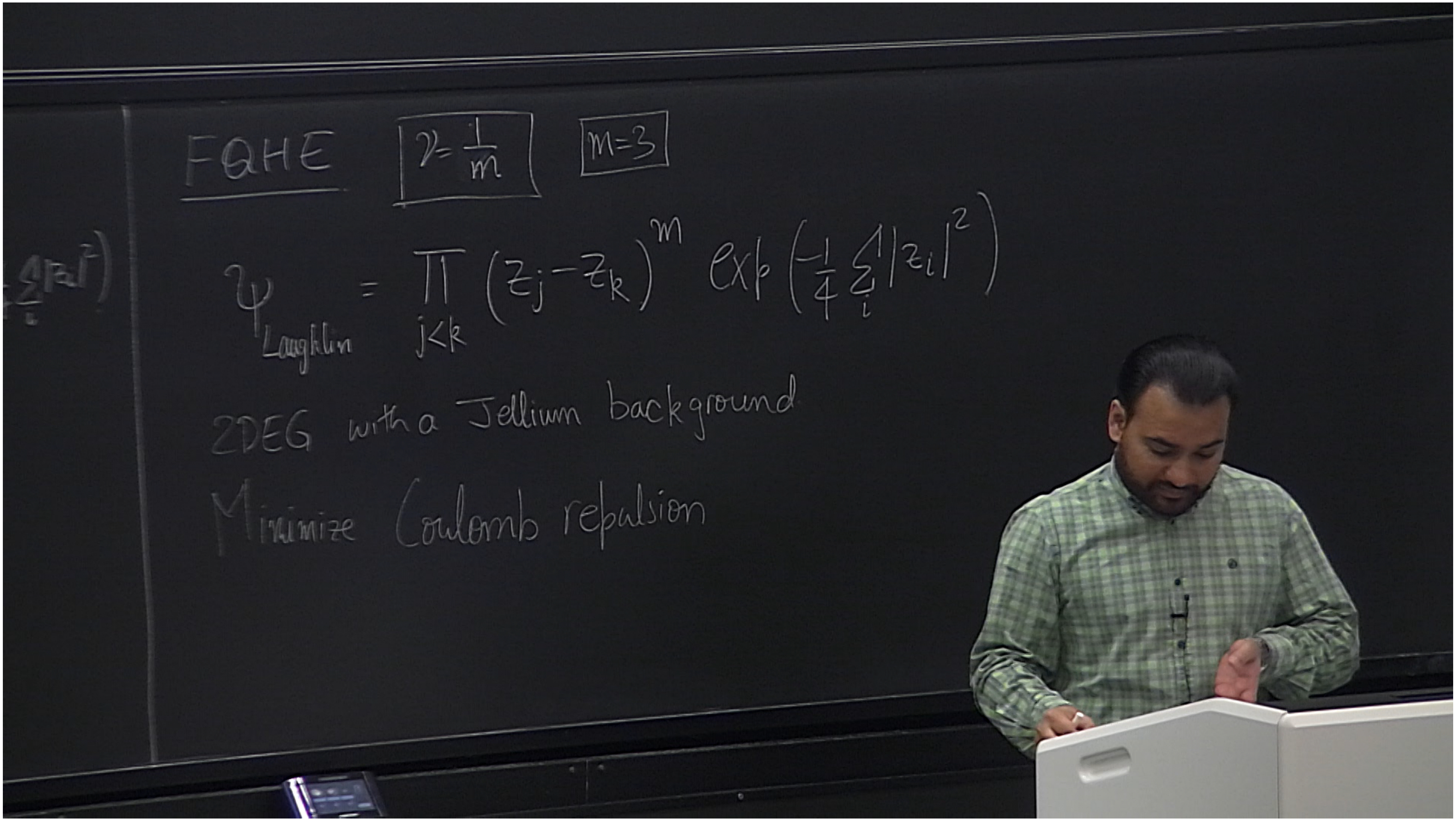
$$\Phi_{LLL}(z_1) = (z_1 - z_2)(z_1 - z_3) \cdots (z_1 - z_N)(\cdots\cdots) \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$$

$= \text{Polynomial in } z_1 \text{ order } N-1$

$$R_H = \frac{h}{fe^2} \qquad f = \nu = \frac{1}{3}, \frac{2}{3}, \frac{2}{5}, \frac{3}{5}, \frac{3}{7}, \ldots$$


FQHE
$\nu = \frac{1}{m}$
$m=3$


FQHE
$\boxed{\nu = \frac{1}{m}}$
$\boxed{m=3}$
$\psi_{\text{Laughlin}} = \prod_{j<k} (z_j - z_k)^m \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$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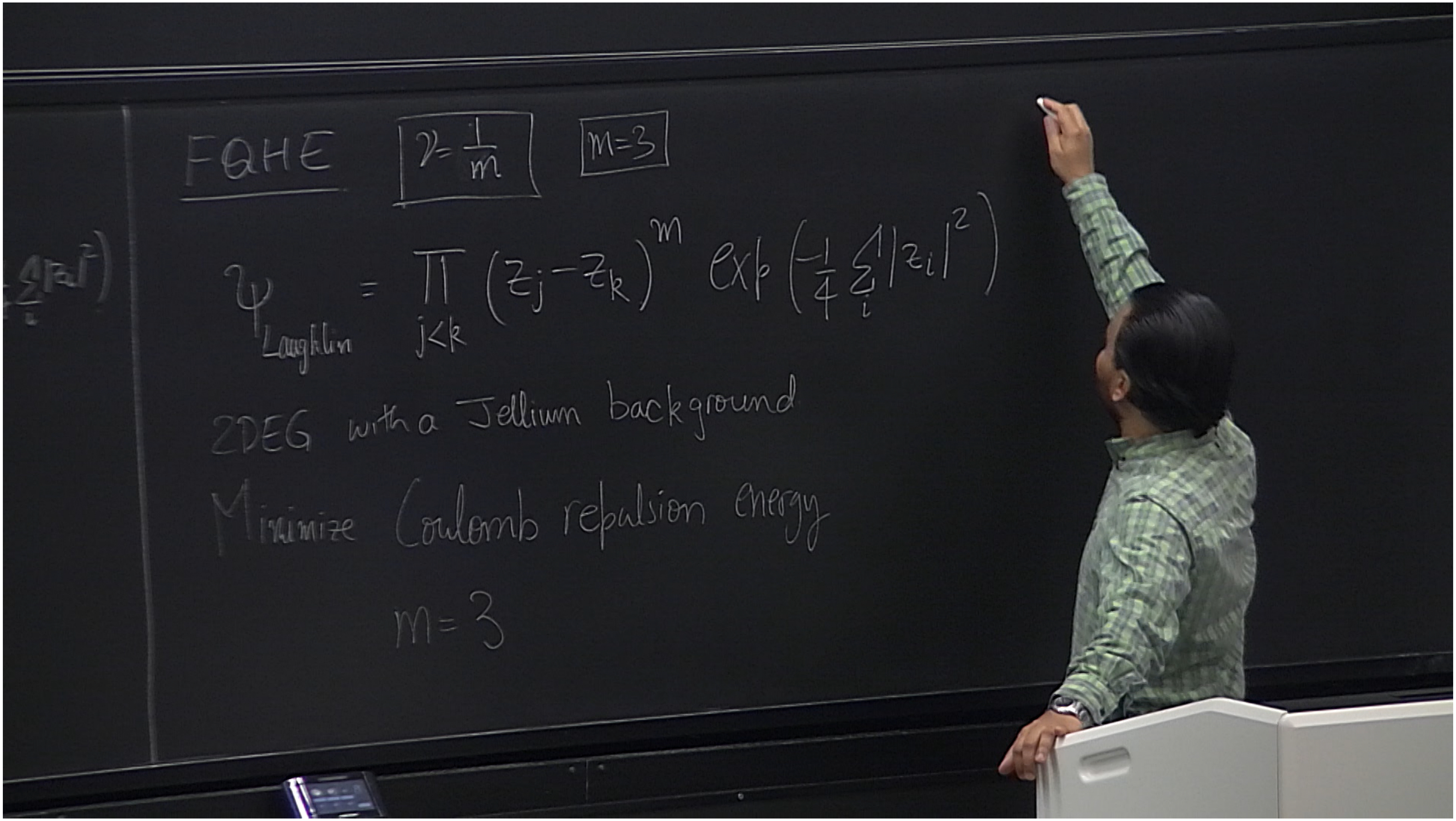
2DEG with a Jellium background
Minimize Coulomb repulsion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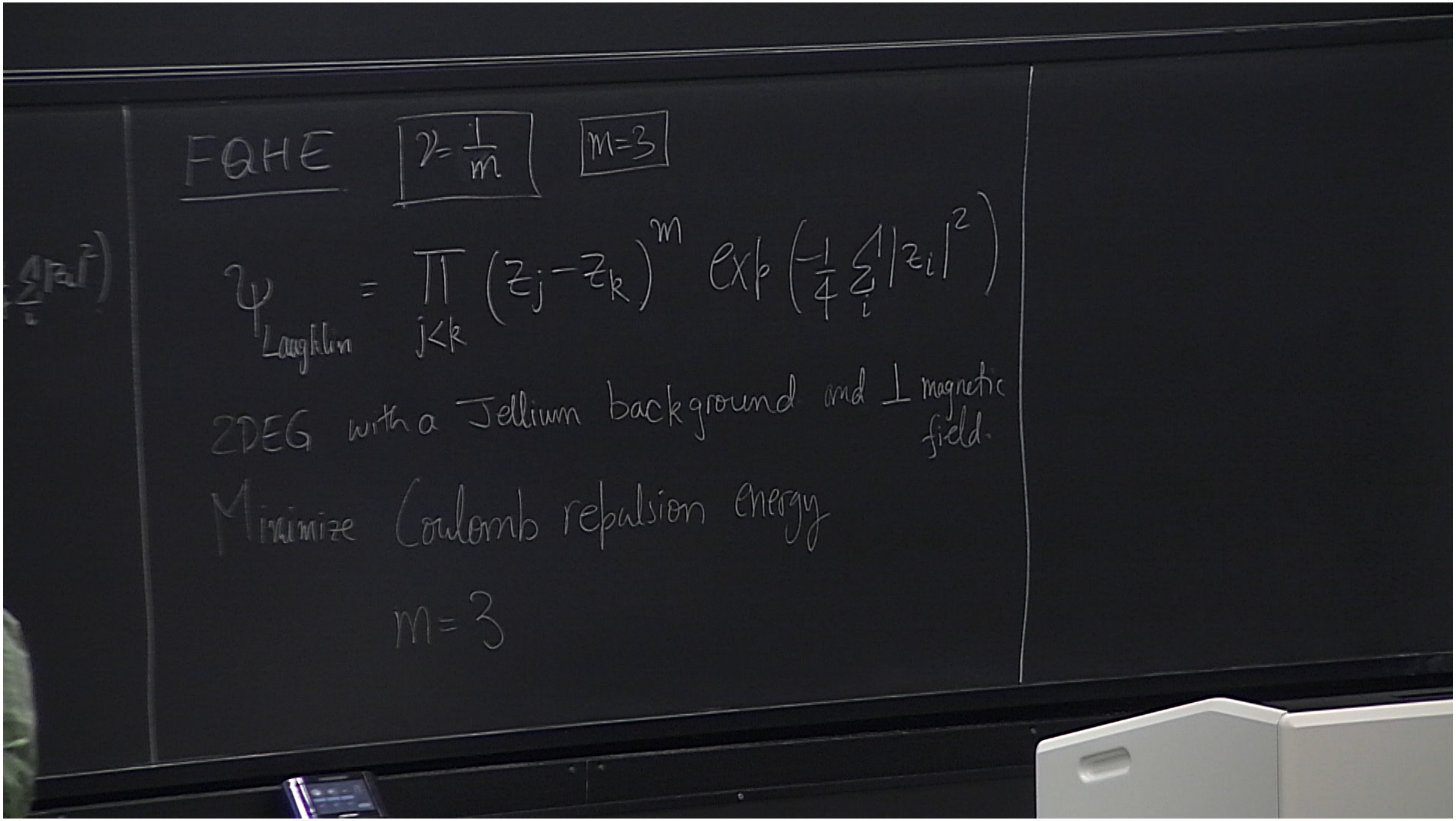
2DEG with a Jellium background
Minimize Coulomb repulsion energy
$m=3$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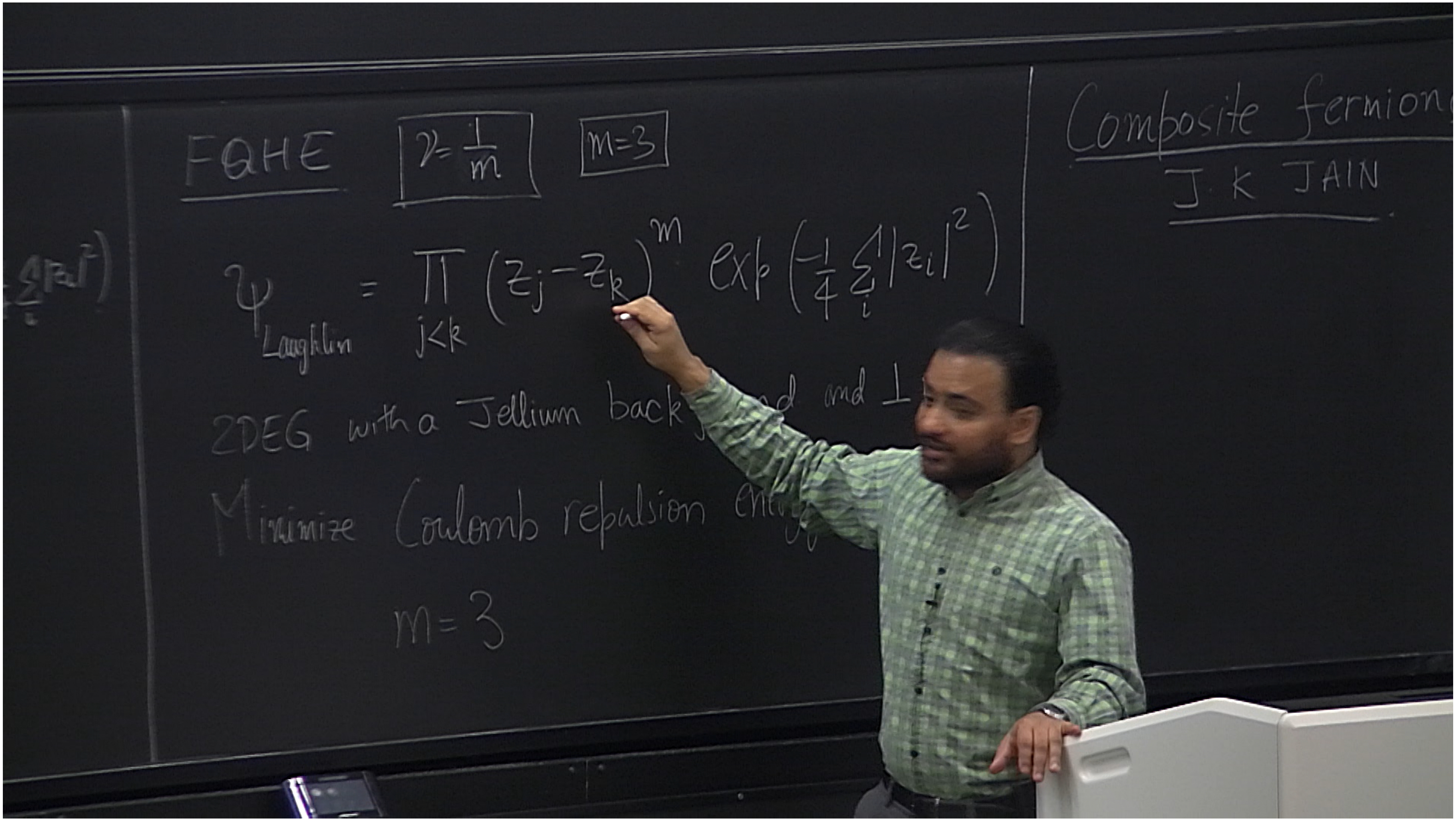
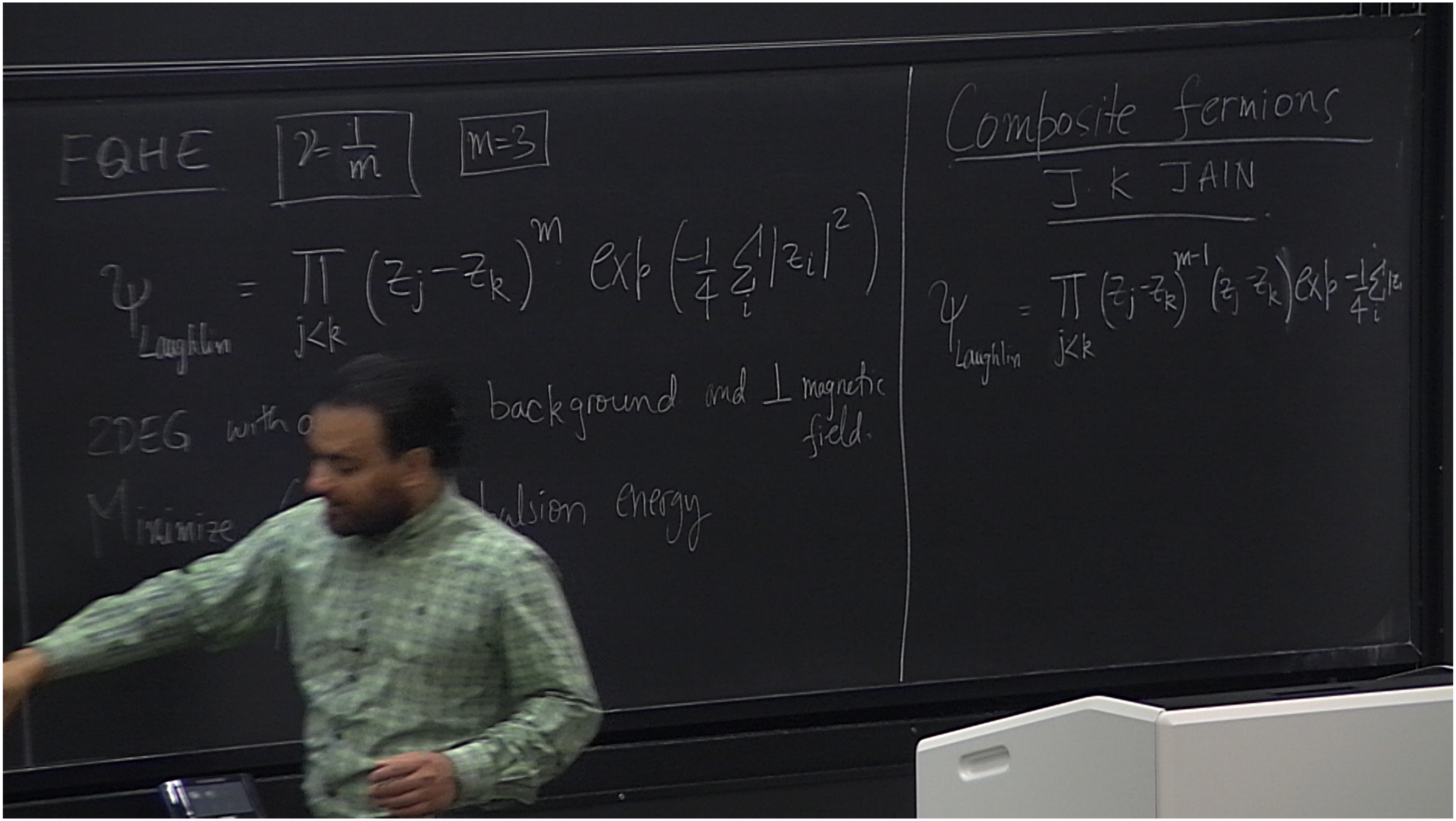
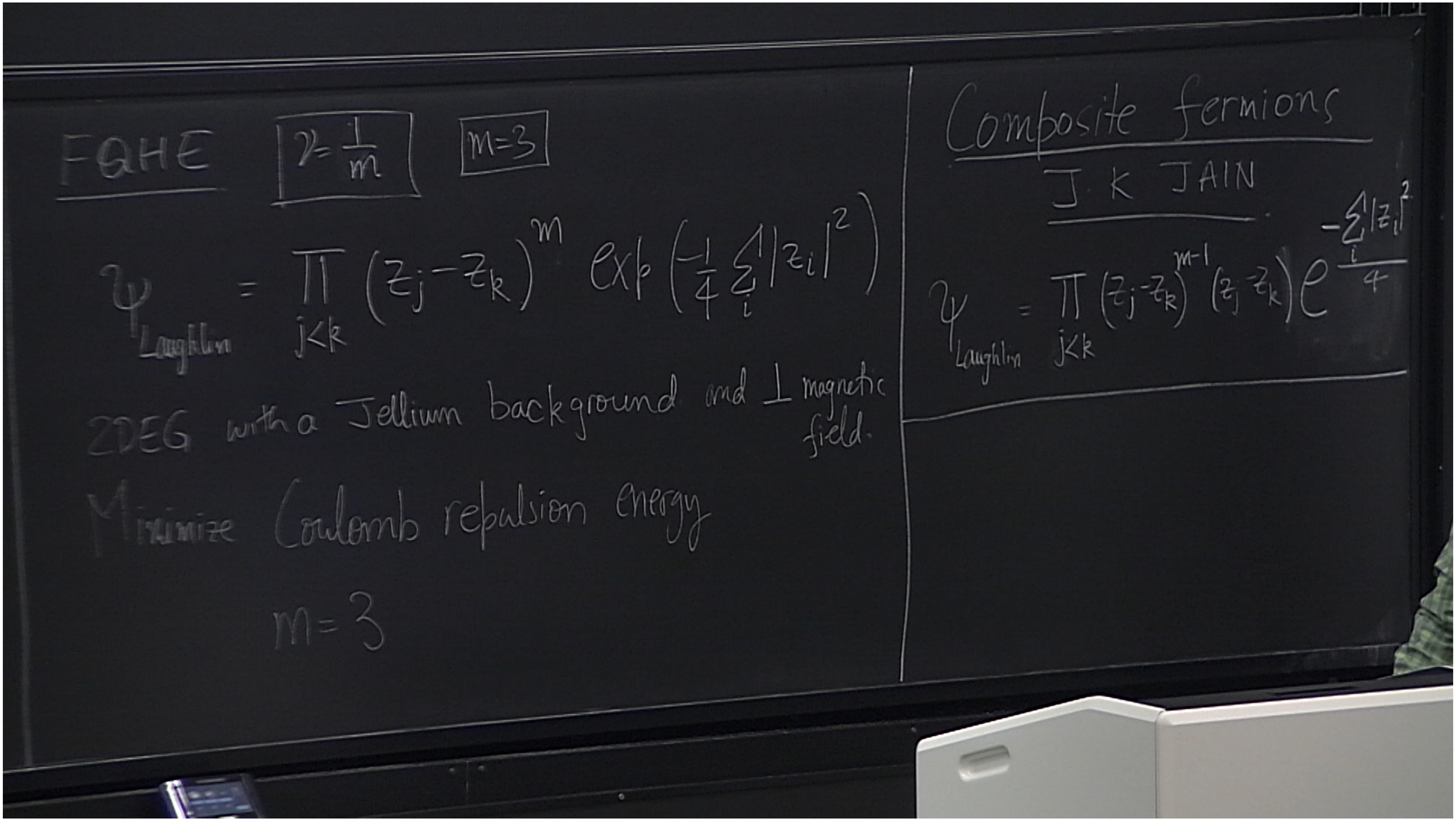
$\psi_{\text{Laughlin}} = \prod_{j<k} (z_j - z_k)^m \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$
2DEG with a Jellium background and ⊥ magnetic field.
Minimize Coulomb repulsion energy
$m=3$


FQHE
$\nu = \frac{1}{m}$
$m=3$
Composite
J. K JAIN
$\psi_{\text{Laughlin}} = \prod_{j<k} (z_j - z_k)^m \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$
2DEG with a Jellium
Minimize Coulomb repulsion
$m = 3$


FQHE
$\nu = \frac{1}{m}$
$m=3$
$\Psi_{Laughlin} = \prod_{j<k} (z_j - z_k)^m \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$
2DEG with
background and ⊥ magnetic field.
Minimize
energy
Composite fermions
J. K JAIN
$\Psi_{Laughlin} = \prod_{j<k} (z_j - z_k)^{m-1} (z_j - z_k) \exp -\frac{1}{4}\sum_i |z_i$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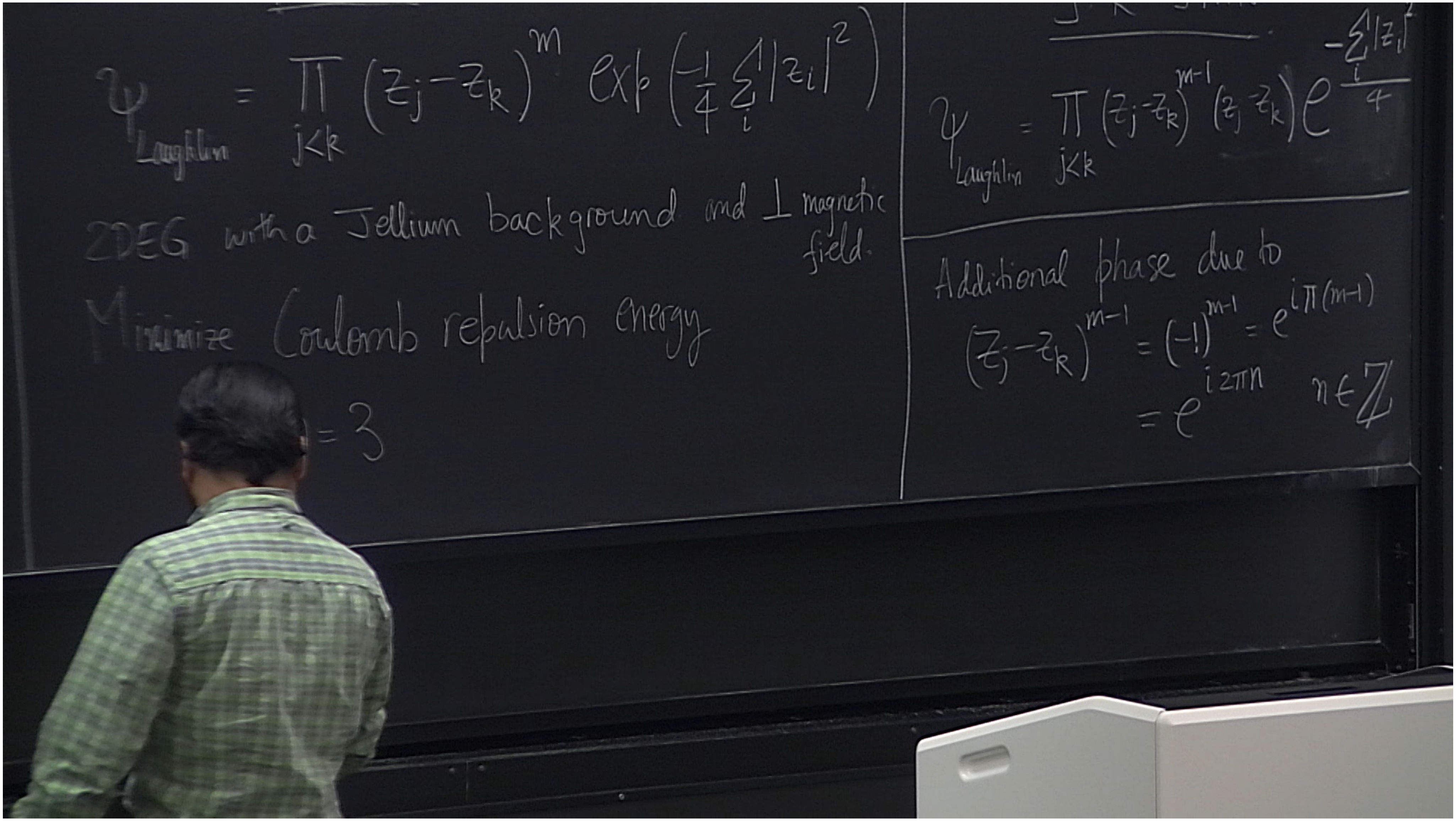
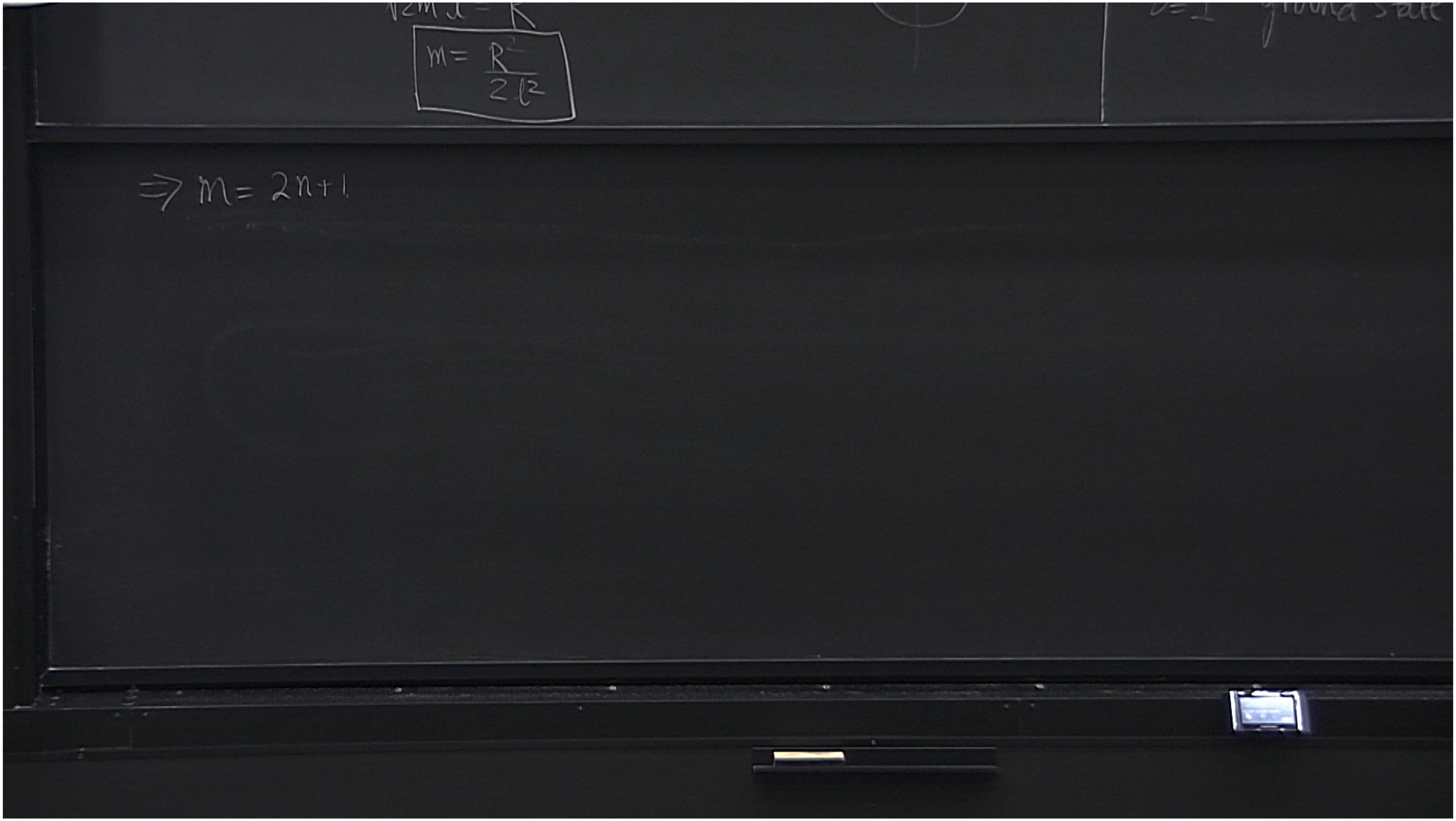
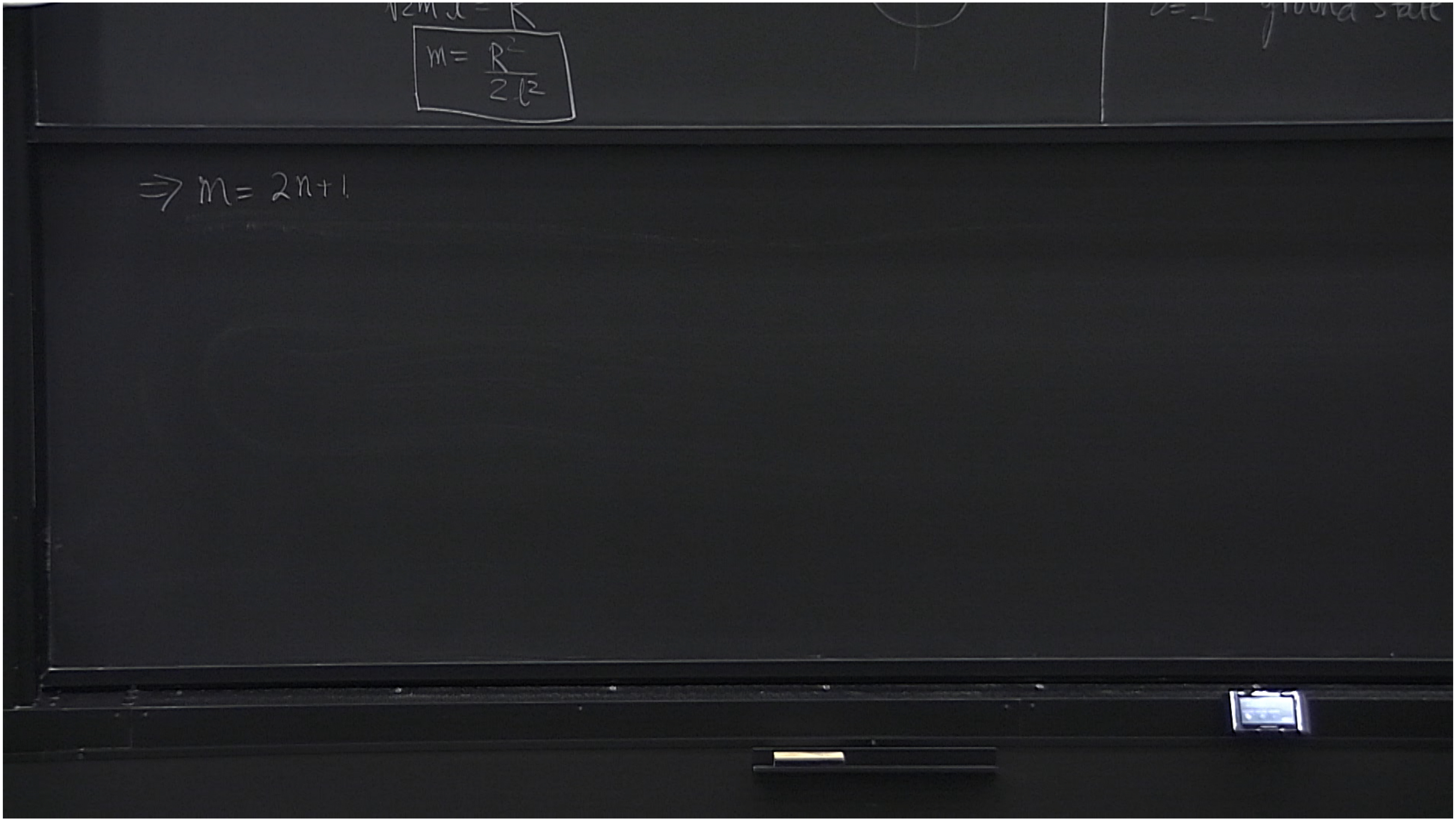
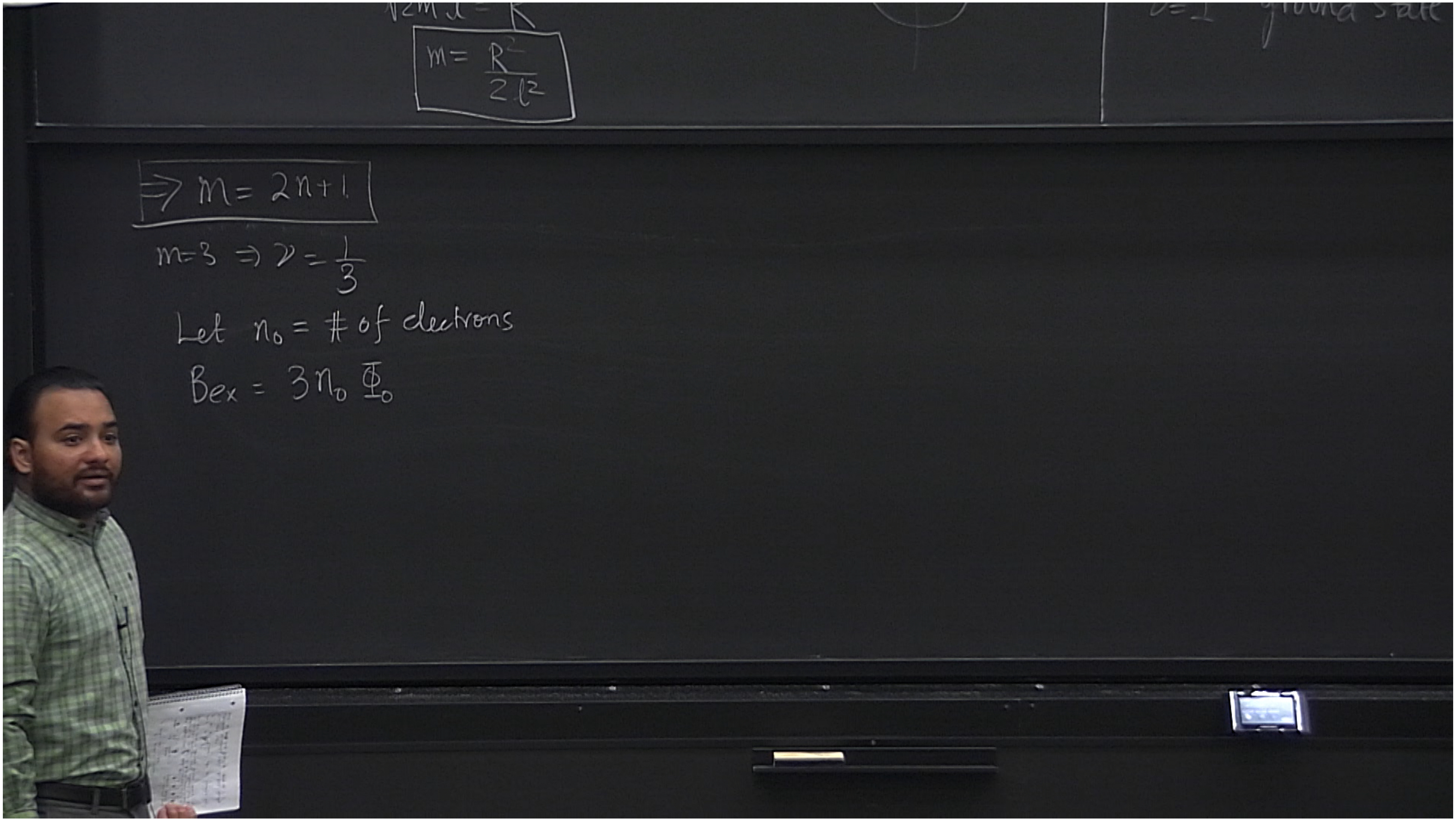
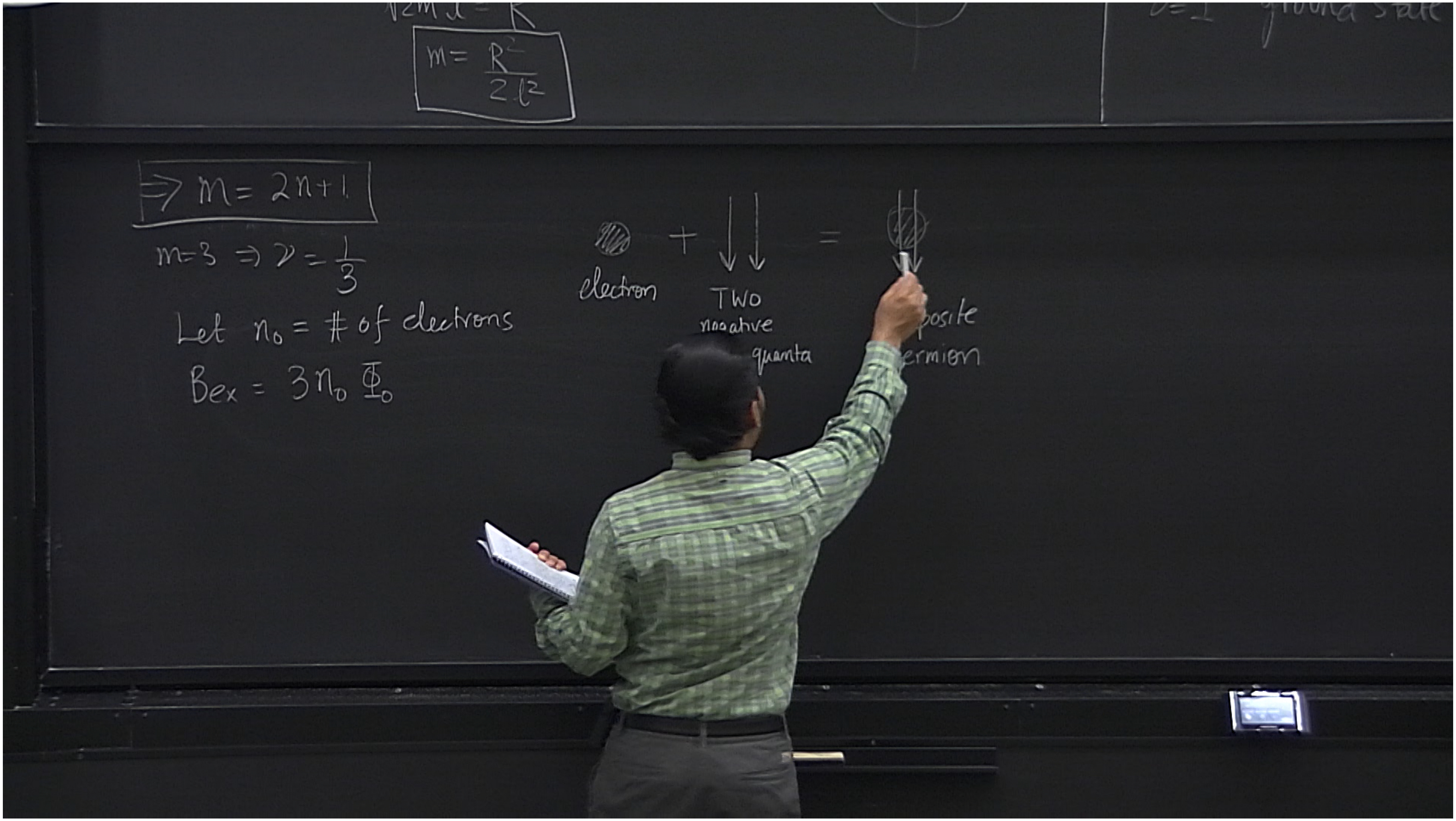
2DEG with a Jellium background and ⊥ magnetic field.
Minimize Coulomb repulsion energy
$m=3$
Composite fermions
J. K JAIN
$\Psi_{Laughlin} = \prod_{j<k} (z_j - z_k)^{m-1} (z_j - z_k) e^{-\frac{\sum_i |z_i|^2}{4}}$

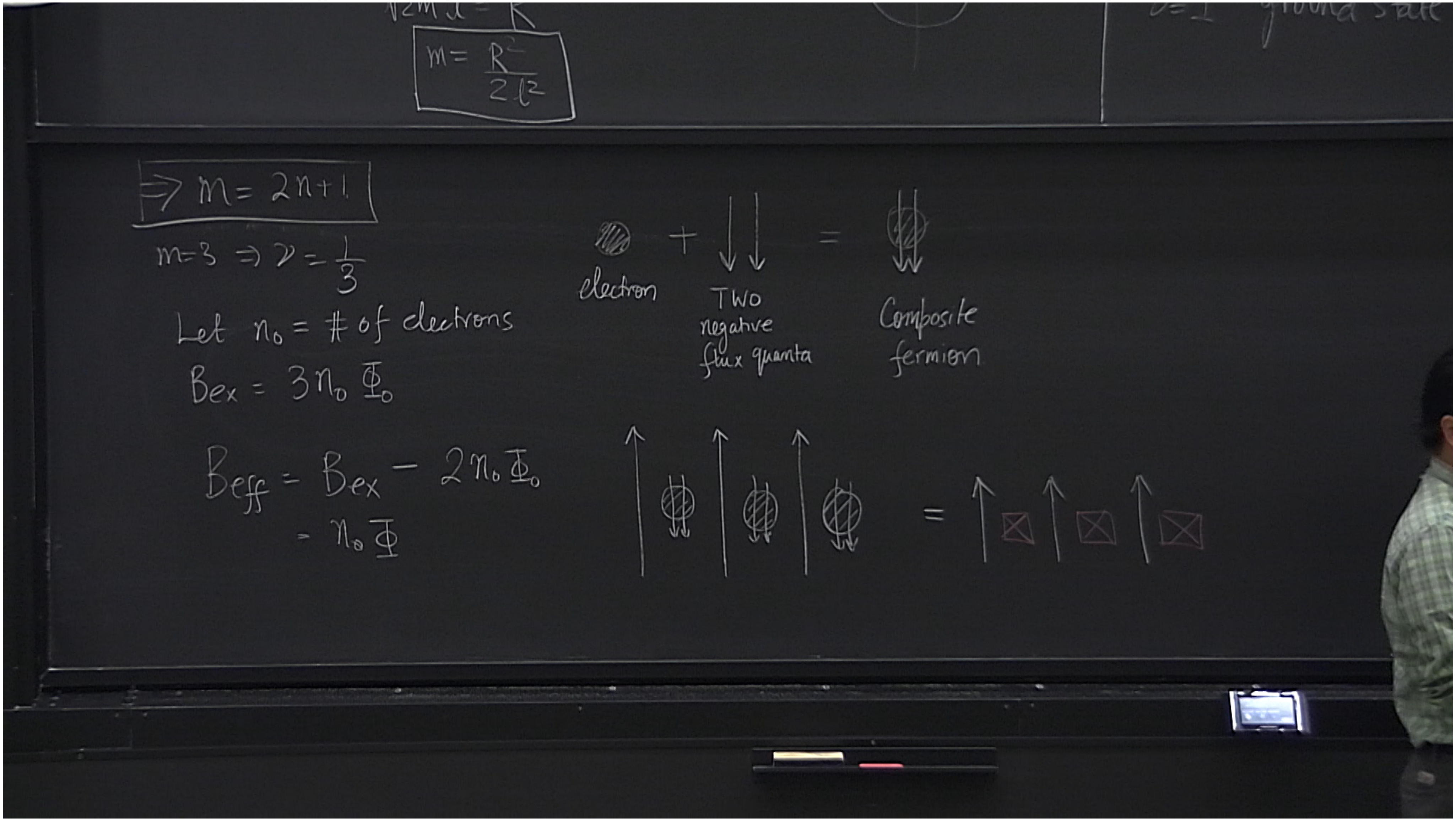

$\psi_{\text{Laughlin}} = \prod_{j<k} (z_j - z_k)^m \exp\left(-\frac{1}{4}\sum_i |z_i|^2\right)$
2DEG with a Jellium background and $\perp$ magnetic field.
Minimize Coulomb repulsion energy
$= 3$
$\psi_{\text{Laughlin}} = \prod_{j<k} (z_j - z_k)^{m-1} (z_j - z_k)\, e^{-\frac{\sum_i |z_i|^2}{4}}$
Additional phase due to
$(z_j - z_k)^{m-1} = (-1)^{m-1} = e^{i\pi(m-1)}$
$= e^{i2\pi n}$ $n \in \mathbb{Z}$


$m = \frac{R^2}{2\ell^2}$
ground state
$\Rightarrow m = 2n+1$


$m = \frac{R^2}{2l^2}$
$\Rightarrow m = 2n+1$


$m = \frac{R^2}{2l^2}$
$\Rightarrow m = 2n+1$
$m=3 \Rightarrow \nu = \frac{1}{3}$
Let n_0 = # of electrons
$B_{ex} = 3 n_0 \Phi_0$


m = R²/2l²
⇒ m = 2n+1
m=3 ⇒ ν = 1/3
Let n₀ = # of electrons
Bex = 3 n₀ Φ₀
electron
TWO
quanta


$m = \frac{R^2}{2l^2}$
$\Rightarrow m = 2n+1$
$m=3 \Rightarrow \nu = \frac{1}{3}$
Let n_0 = # of electrons
$B_{ex} = 3 n_0 \Phi_0$
$B_{eff} = B_{ex} - 2 n_0 \Phi_0$
$= n_0 \Phi$
electron
TWO negative flux quanta
Composite fermion

=1 ground state is unique

Vandermonde determinant

for a general value of m

Composite fermion = electron + $(m-1)$ Negative flux quanta ground state is unique

Vandermonde determinant

for a general value of m

Composite fermion = electron + (m−1) Negative flux quanta

$$\nu = \frac{1}{3}, \frac{2}{3}, \frac{2}{5}, \frac{3}{5}, \frac{3}{7}$$

ground state is unique

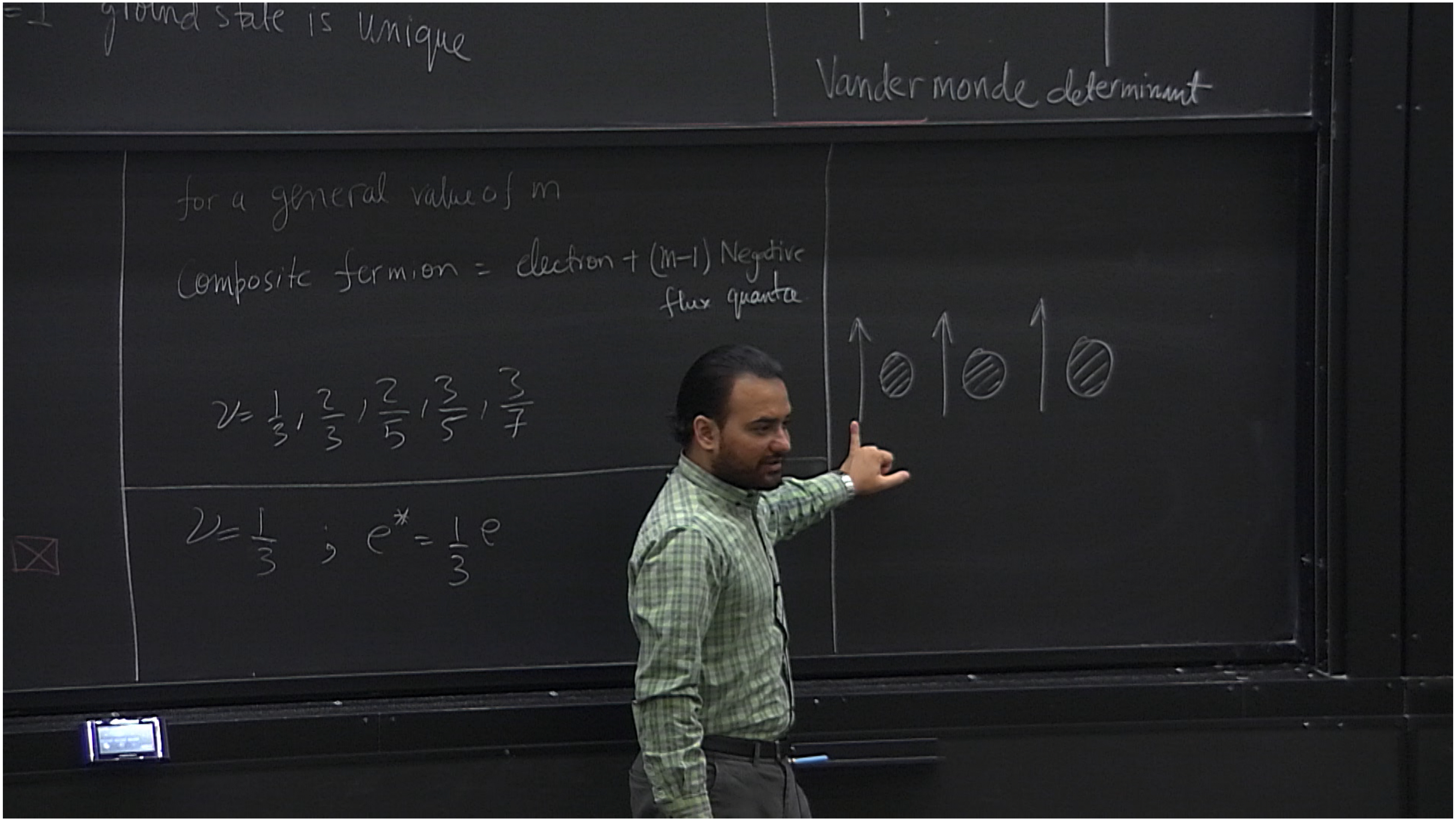
Vandermonde determinant

for a general value of m

Composite fermion = electron + (m−1) Negative flux quanta

$$\nu = \frac{1}{3}, \frac{2}{3}, \frac{2}{5}, \frac{3}{5}, \frac{3}{7}$$

$$\nu = \frac{1}{3} \; ; \; e^* = \frac{1}{3} e$$


ground state is unique
Vandermonde determinant
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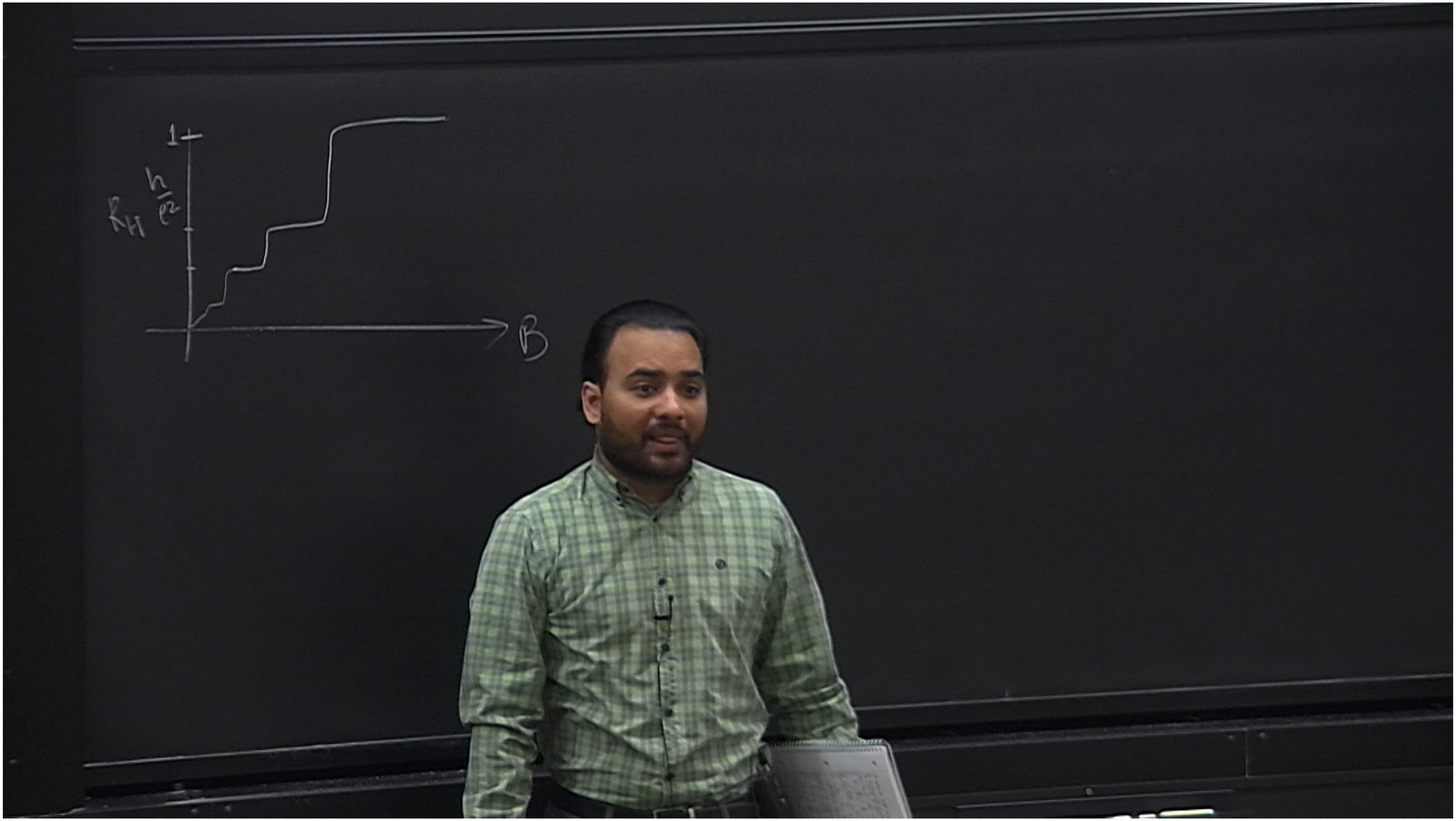
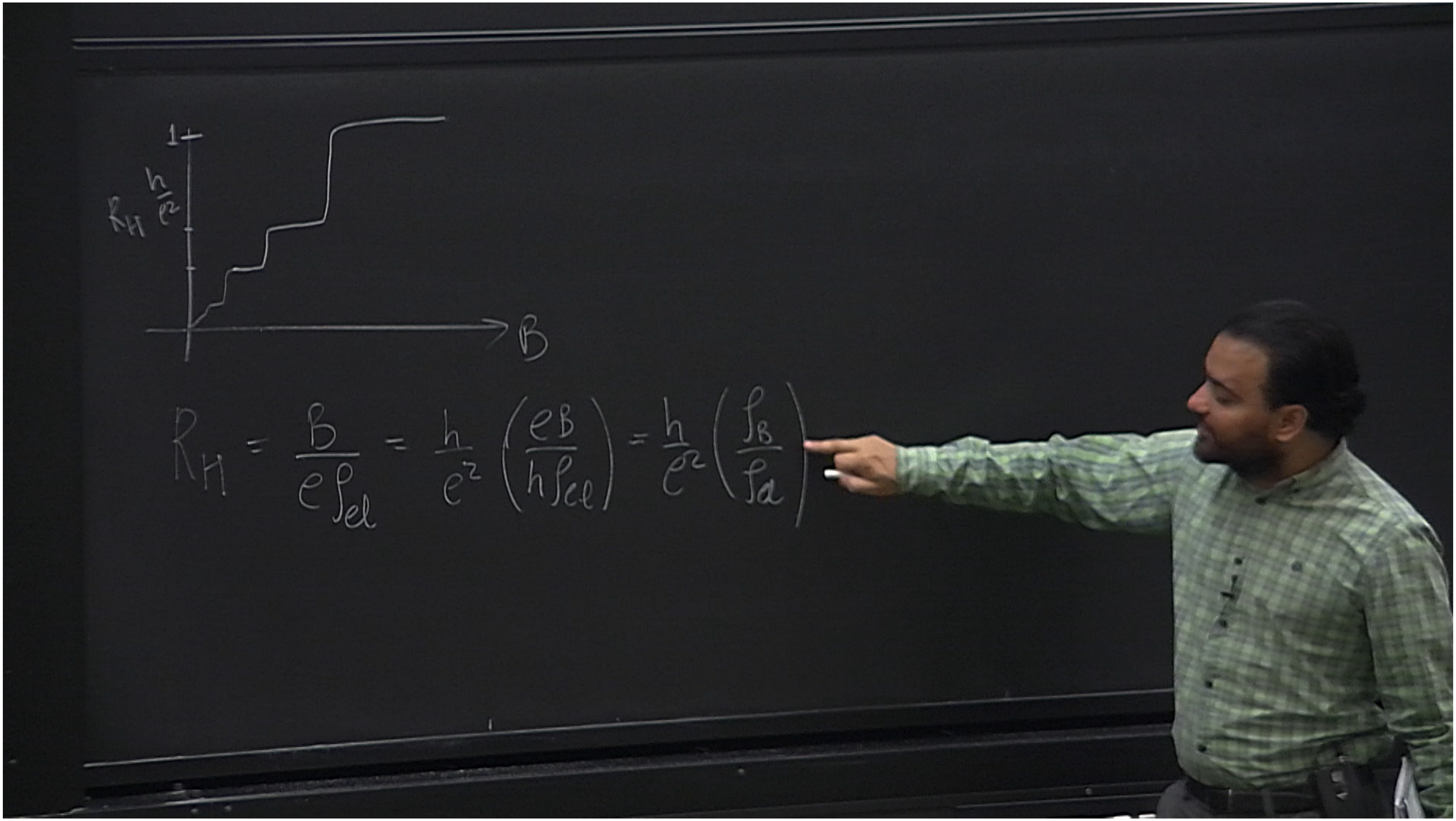
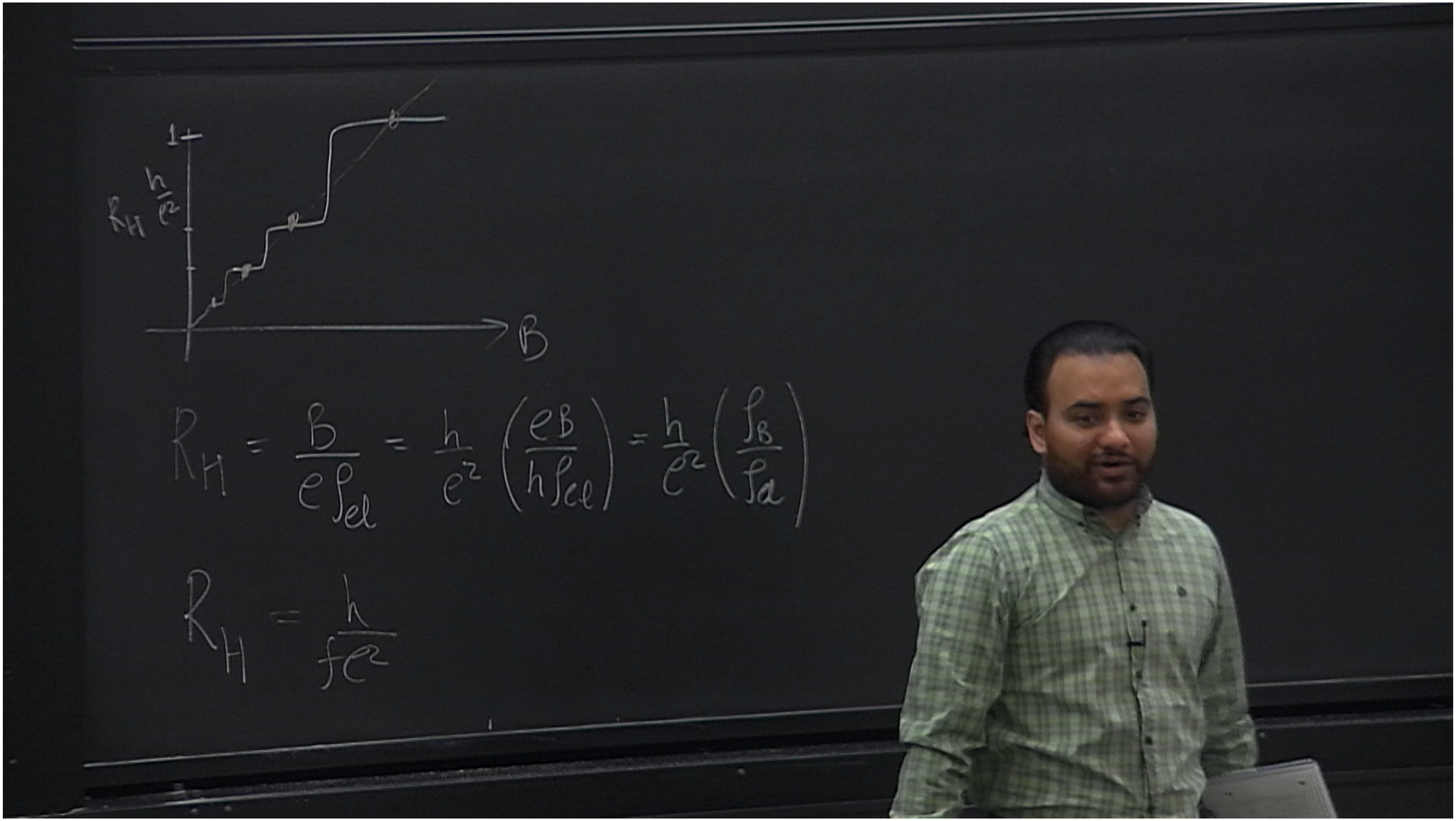


1
$R_H \frac{h}{e^2}$
B


1
$R_H \frac{h}{e^2}$
B
$R_H = \frac{B}{e\rho_{el}} = \frac{h}{e^2}\left(\frac{eB}{h\rho_{el}}\right) = \frac{h}{e^2}\left(\frac{\rho_B}{\rho_{el}}\right)$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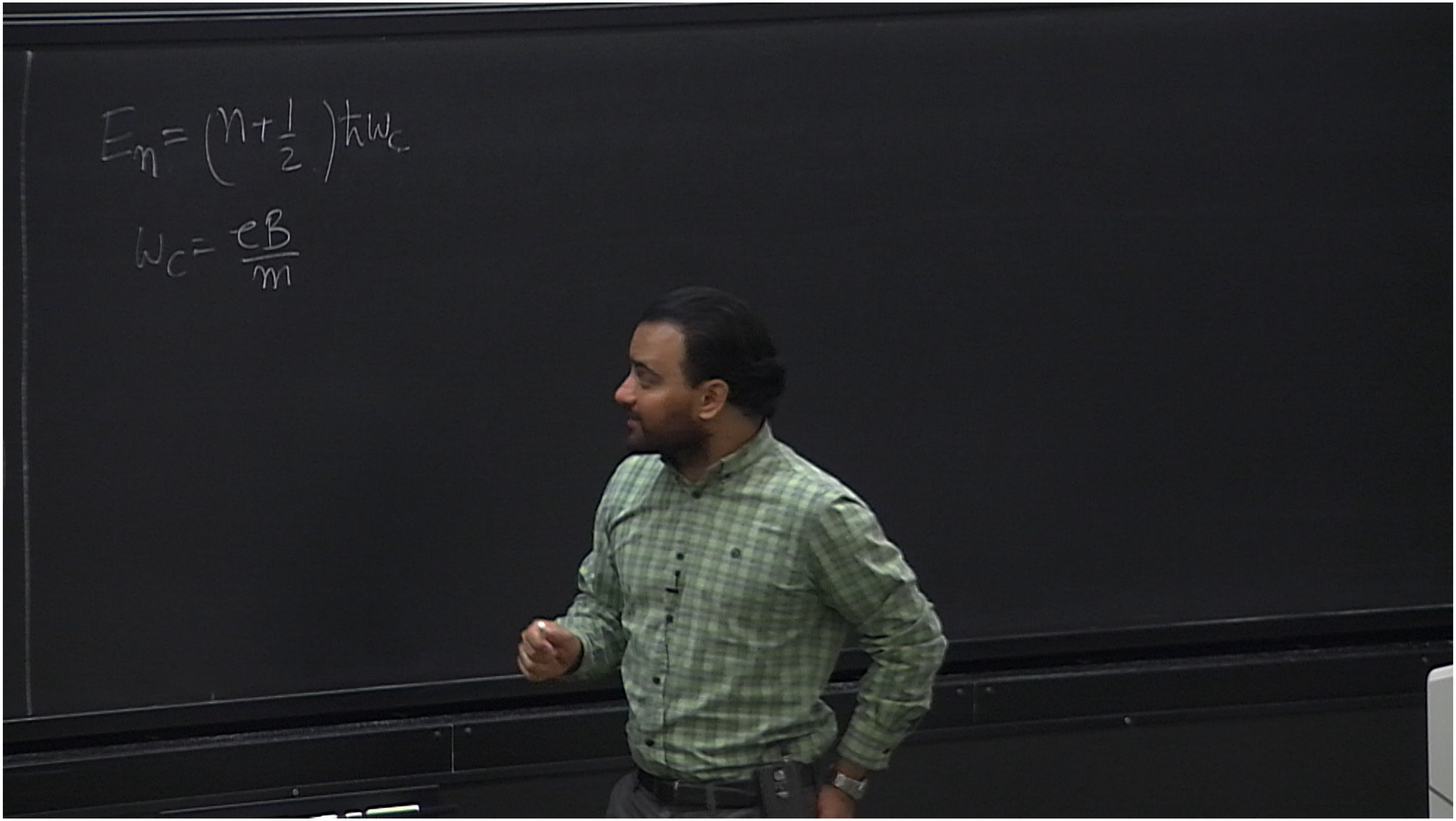
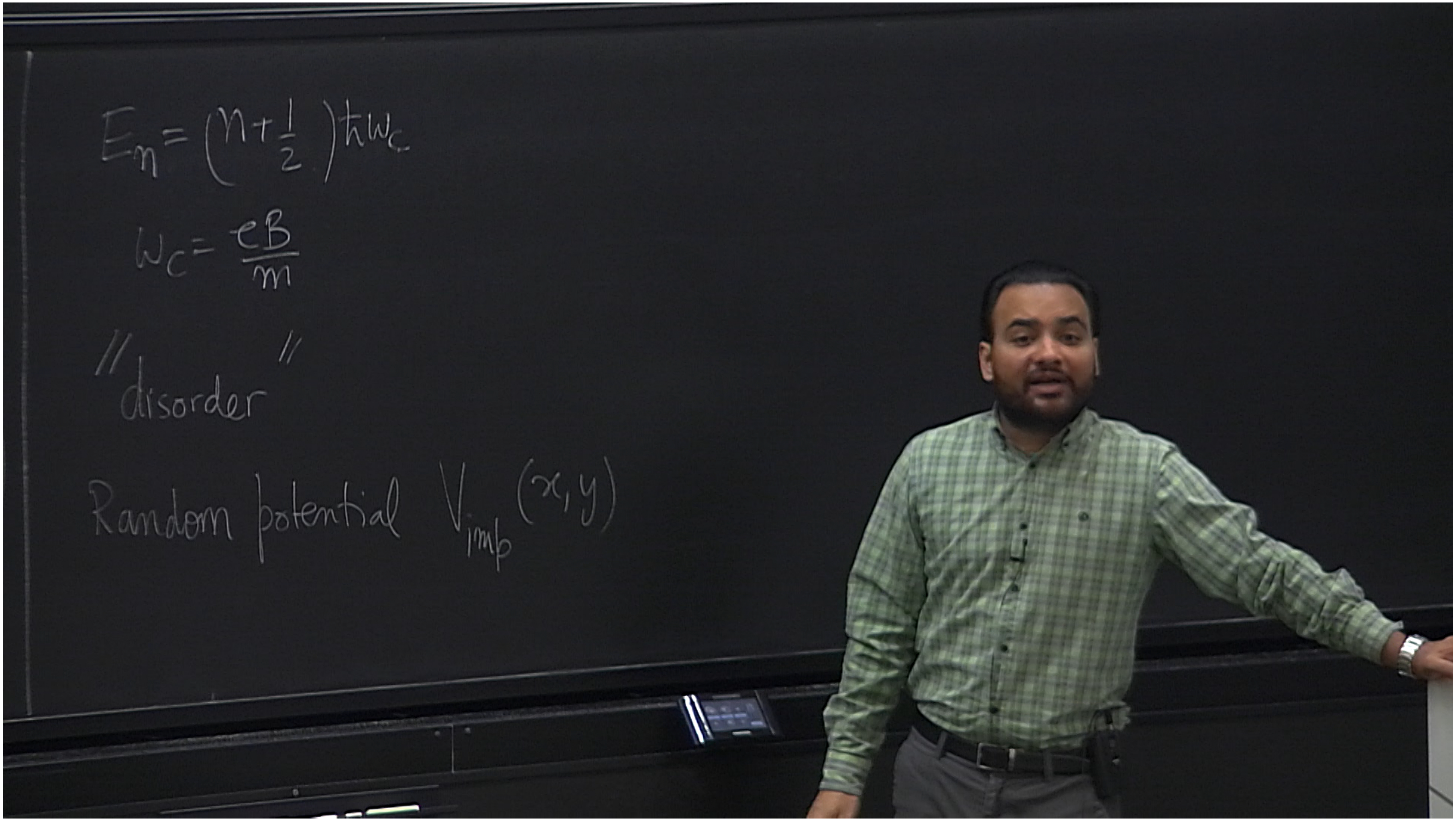
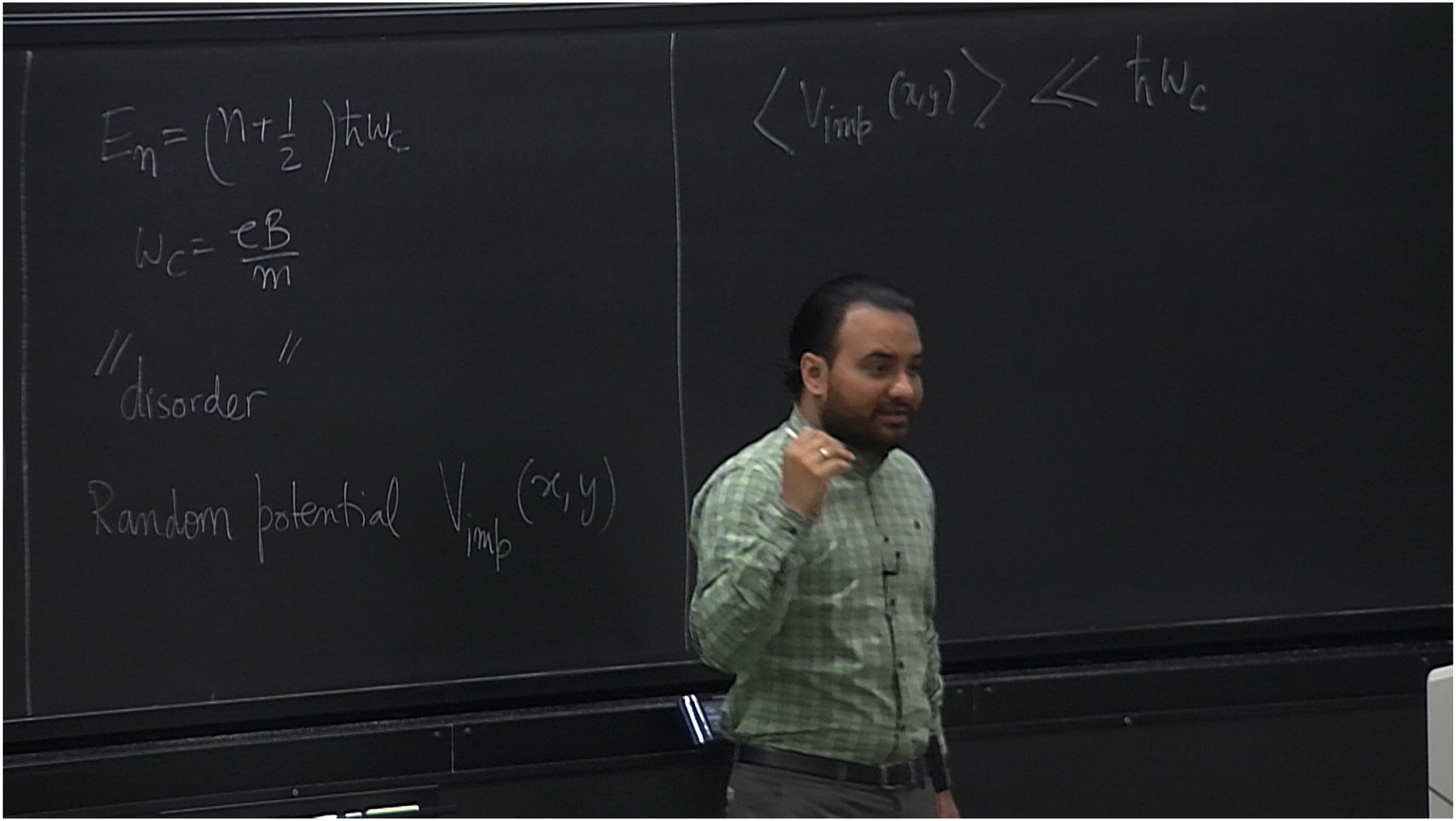
$R_H = \frac{h}{fe^2}$


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


$E_n = \left(n + \frac{1}{2}\right)\hbar\omega_c$
$\omega_c = \frac{eB}{m}$
"disorder"
Random potential $V_{imp}(x, y)$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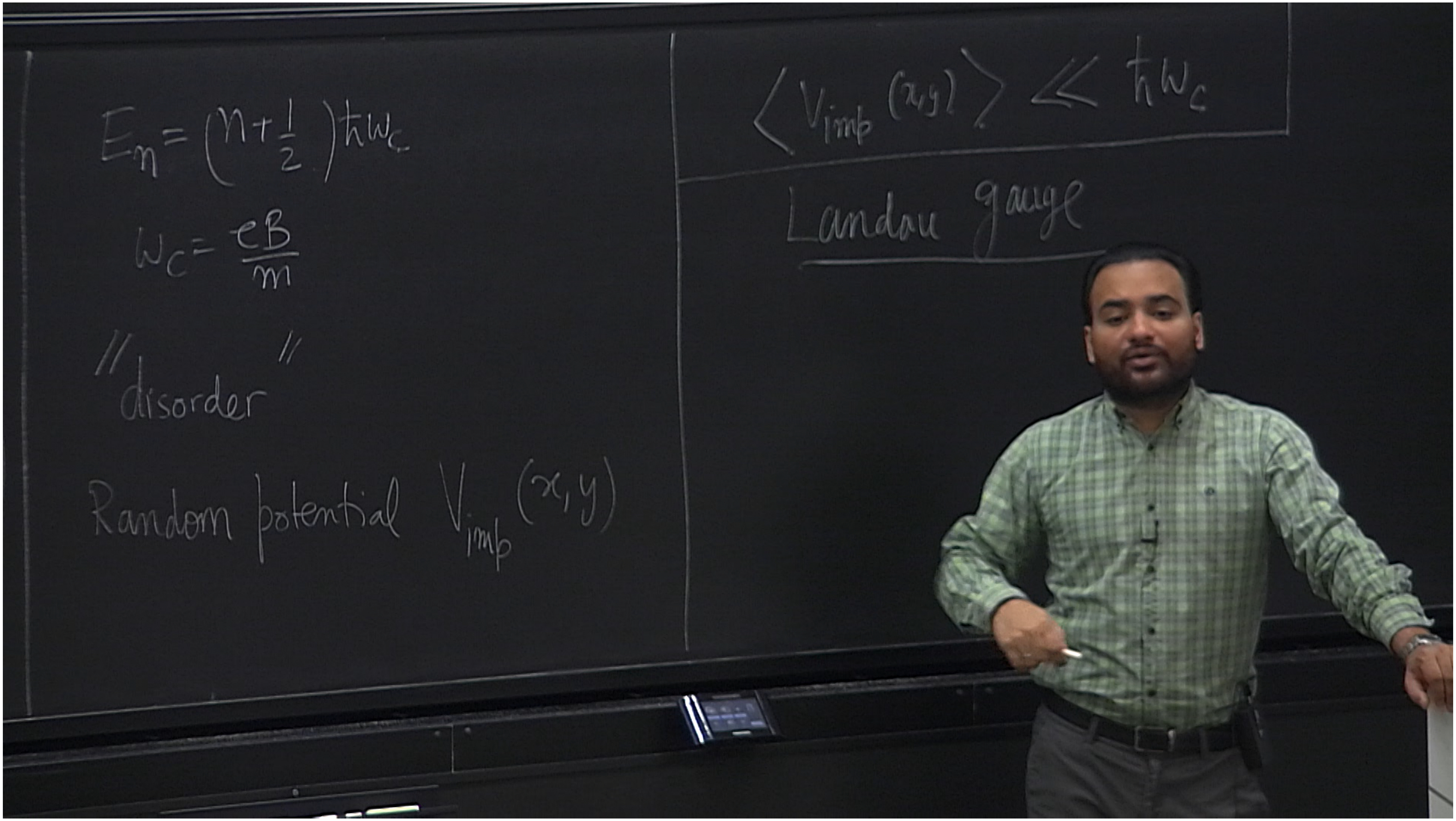
$\langle V_{imp}(x,y) \rangle \ll \hbar\omega_c$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Random potential $V_{imp}(x,y)$
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Landau gauge

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

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

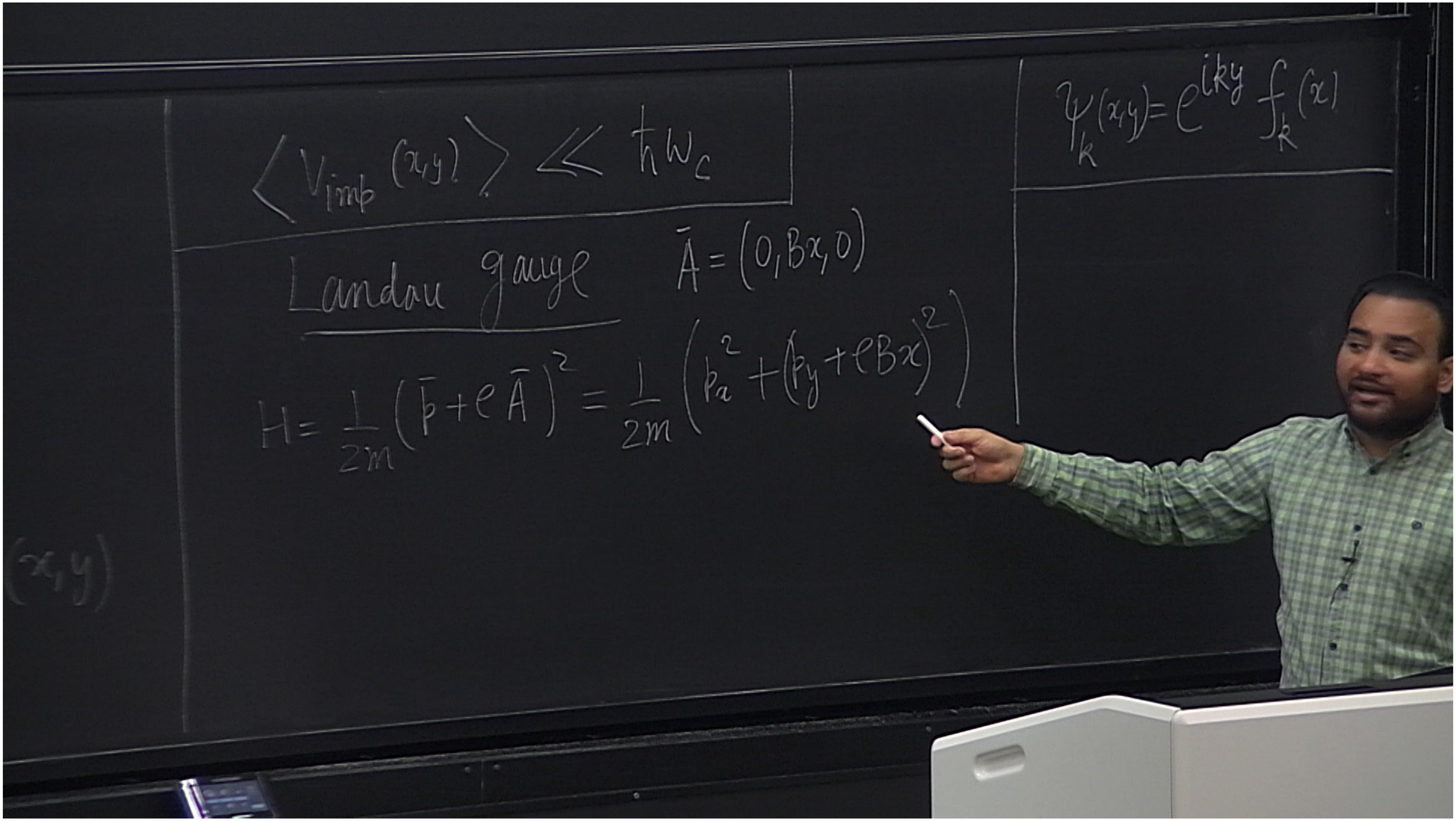
disorder

random potential $V_{imp}(x,y)$

$\langle V_{imp}(x,y)\rangle \ll \hbar\omega_c$

Landau gauge $\bar{A} = (0, Bx, 0)$

$$H = \frac{1}{2m}\left(\bar{p} + e\bar{A}\right)^2 = \frac{1}{2m}\left(p_x^2 + (p_y + eBx)^2\right)$$


$\langle V_{imp}(x,y) \rangle \ll \hbar \omega_c$
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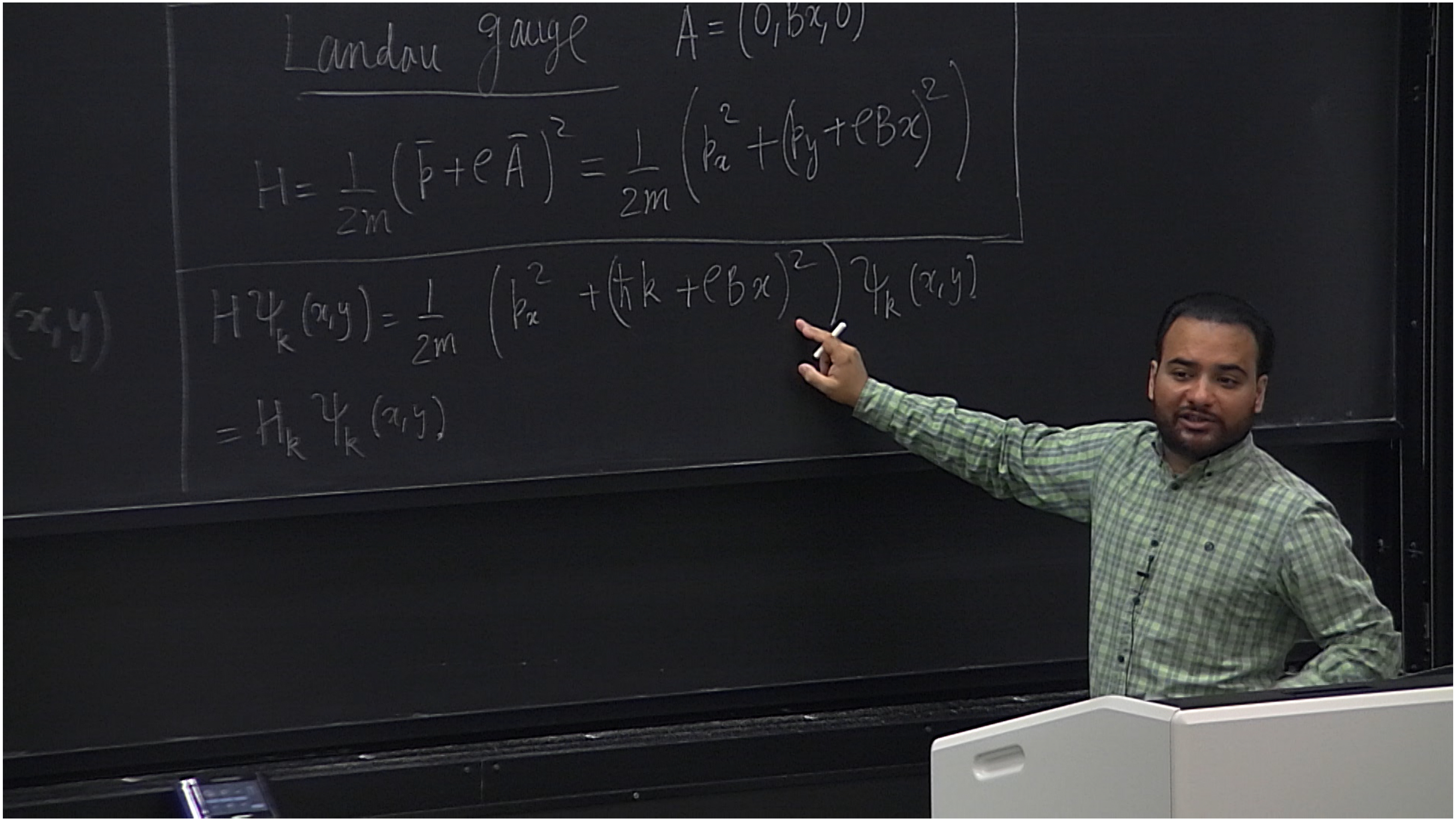
$H = \frac{1}{2m}(\bar{p} + e\bar{A})^2 = \frac{1}{2m}\left(p_x^2 + (p_y + eBx)^2\right)$
$\psi_k(x,y) = e^{iky} f_k(x)$
(x,y)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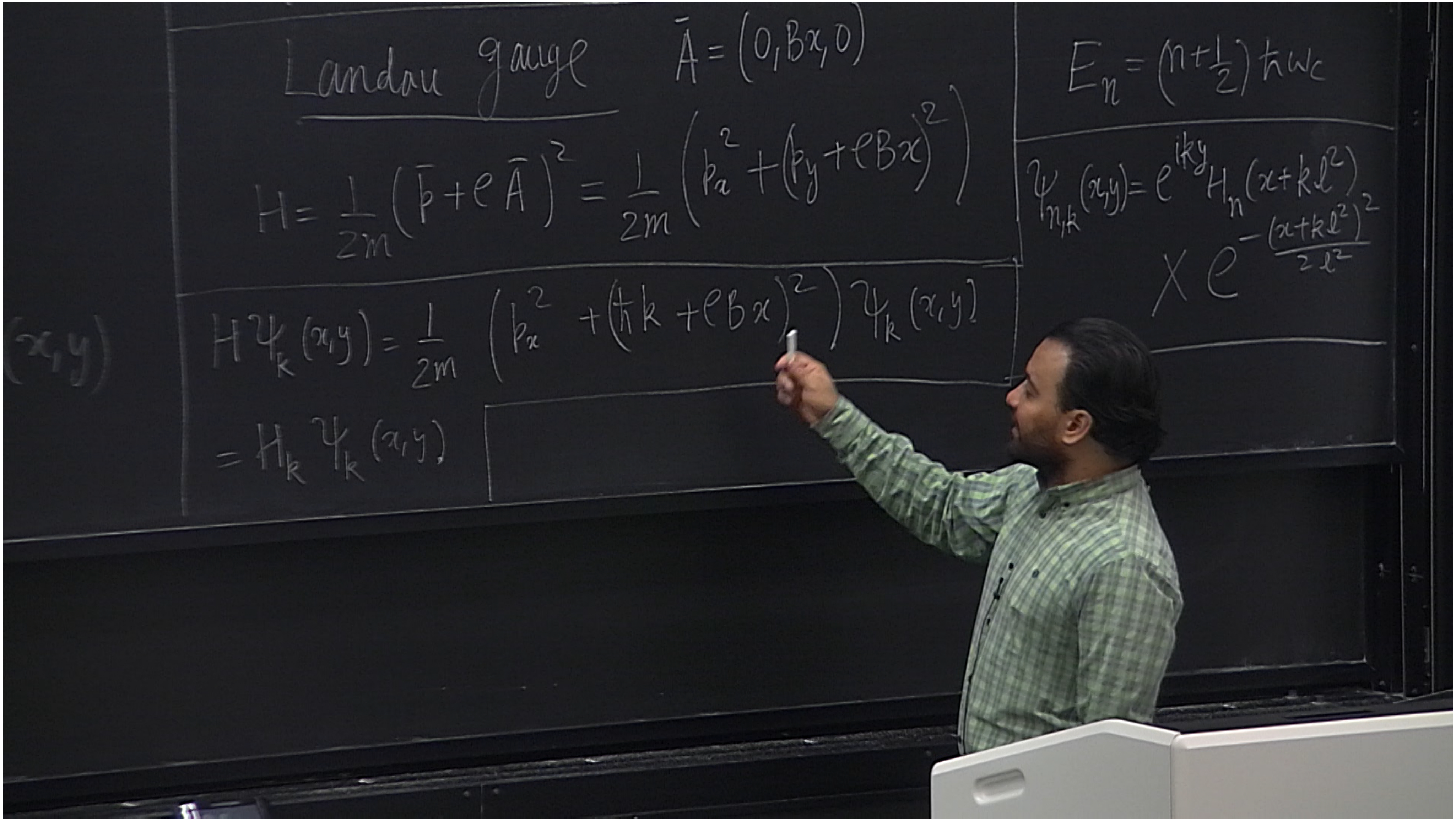
$H = \frac{1}{2m}(\bar{p} + e\bar{A})^2 = \frac{1}{2m}\left(p_x^2 + (p_y + eBx)^2\right)$
$H\psi_k(x,y) = \frac{1}{2m}\left(p_x^2 + (\hbar k + eBx)^2\right)\psi_k(x,y)$
$= H_k \psi_k(x,y)$
(x,y)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$E_n = (n + \frac{1}{2})\hbar\omega_c$
$\psi_{n,k}(x,y) = e^{iky} H_n(x + k\ell^2)$
$\times e^{-\frac{(x+k\ell^2)^2}{2\ell^2}}$
$H\psi_k(x,y) = \frac{1}{2m}\left(p_x^2 + (\hbar k + eBx)^2\right)\psi_k(x,y)$
$= H_k \psi_k(x,y)$
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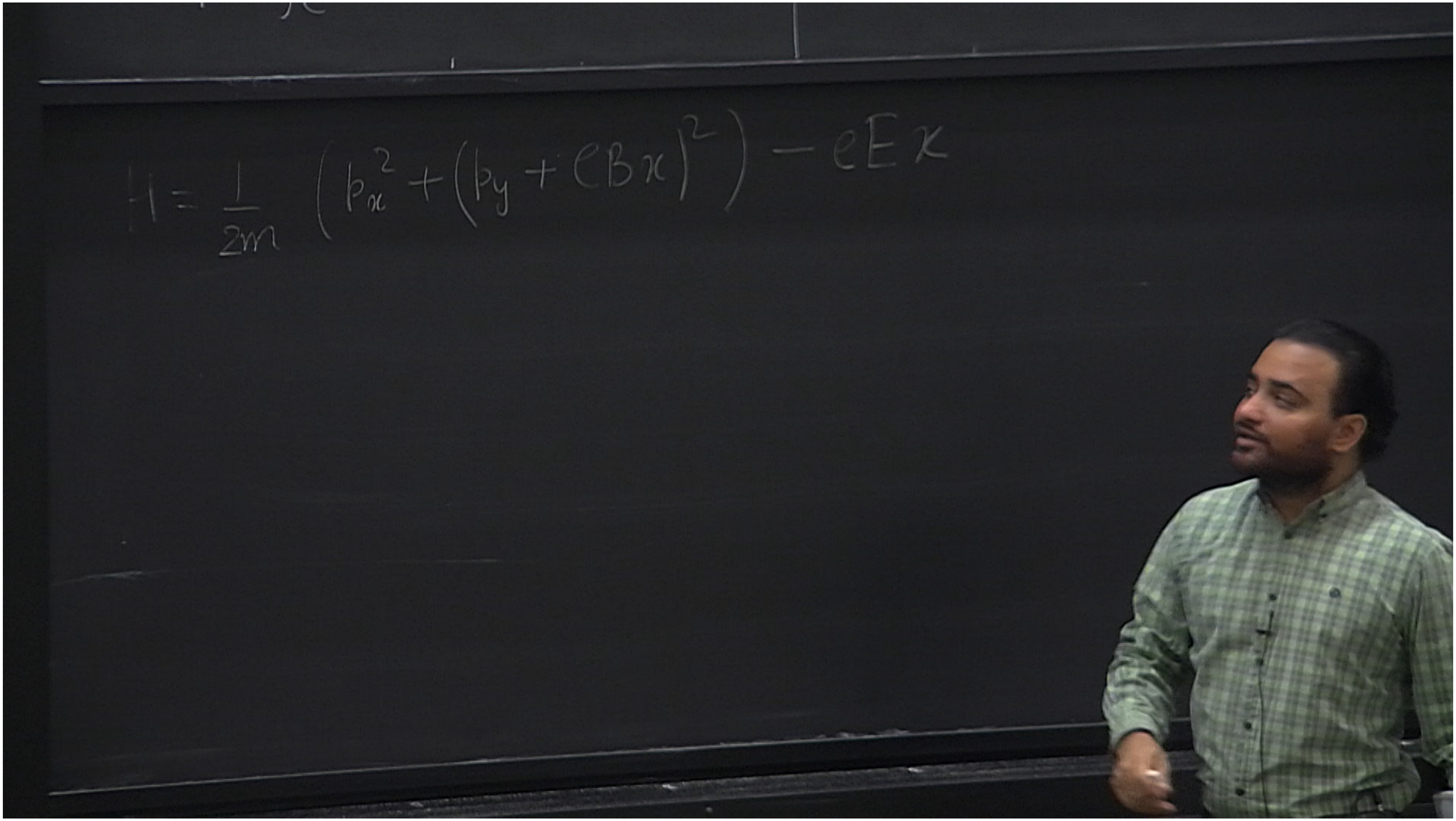
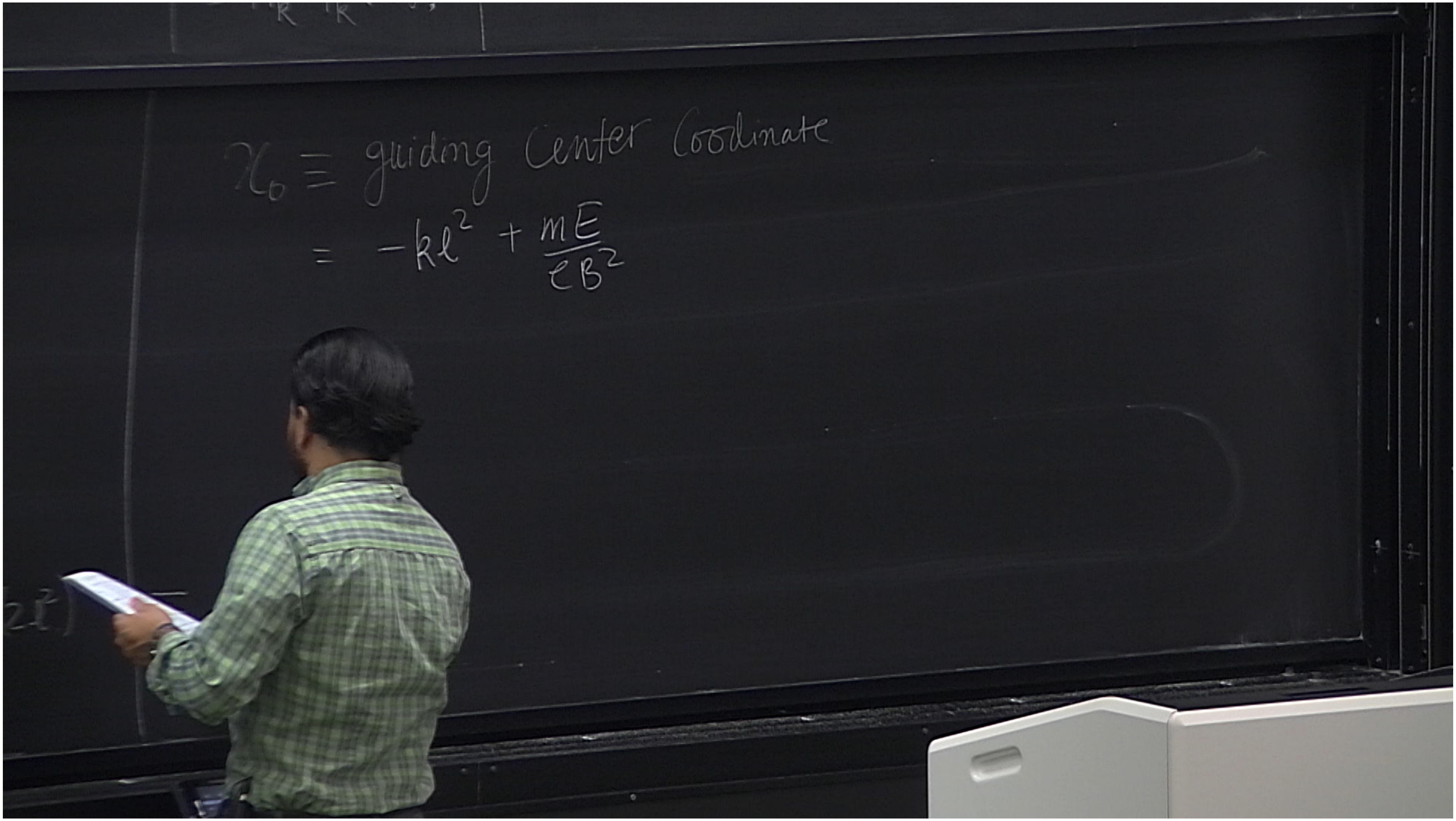

$H = \frac{1}{2m}\left(p_x^2 + (p_y + eBx)^2\right) - eEx$

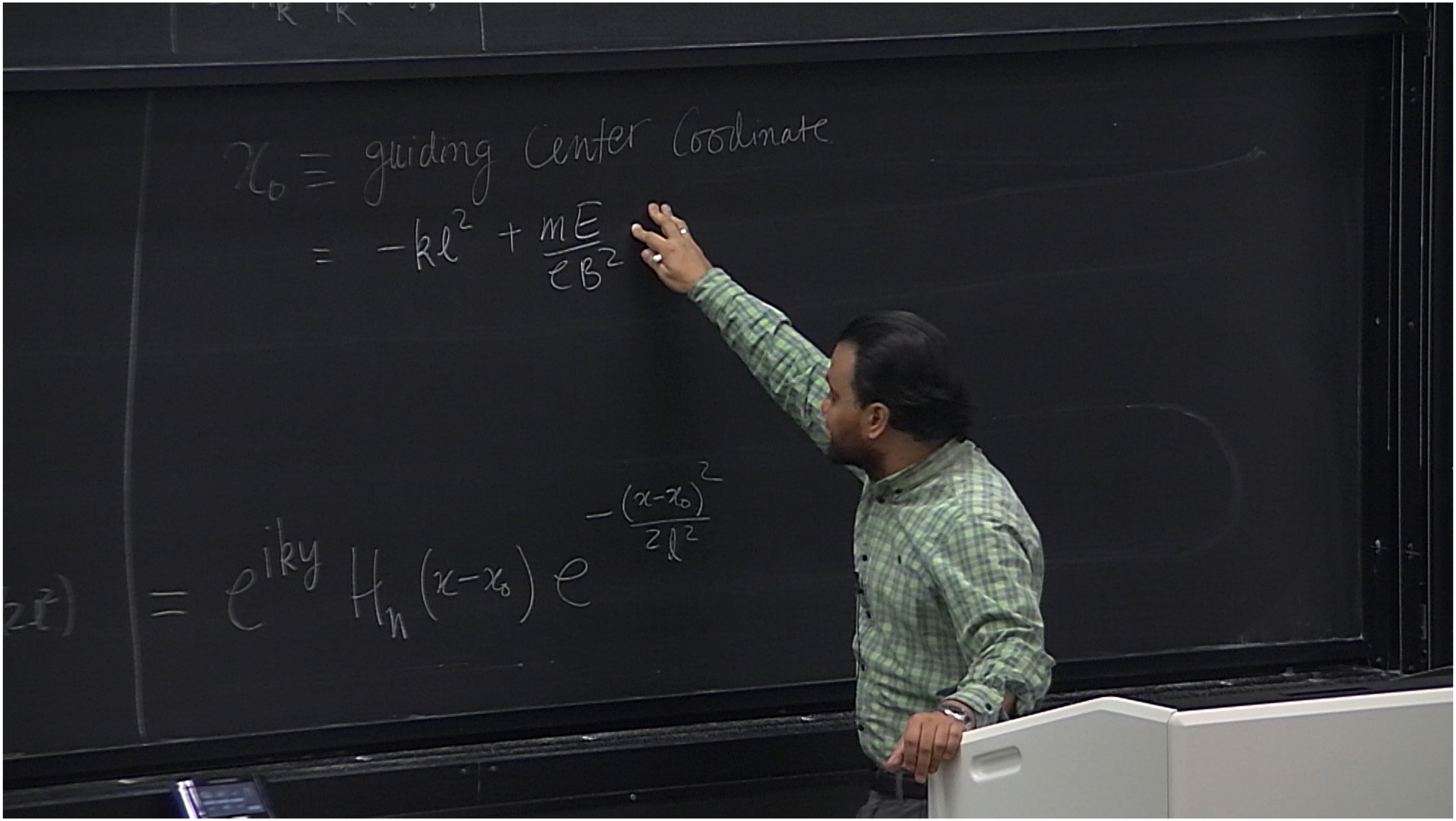
$$H = \frac{1}{2m}\left(p_x^2 + \left(p_y + eBx\right)^2\right) - eEx$$

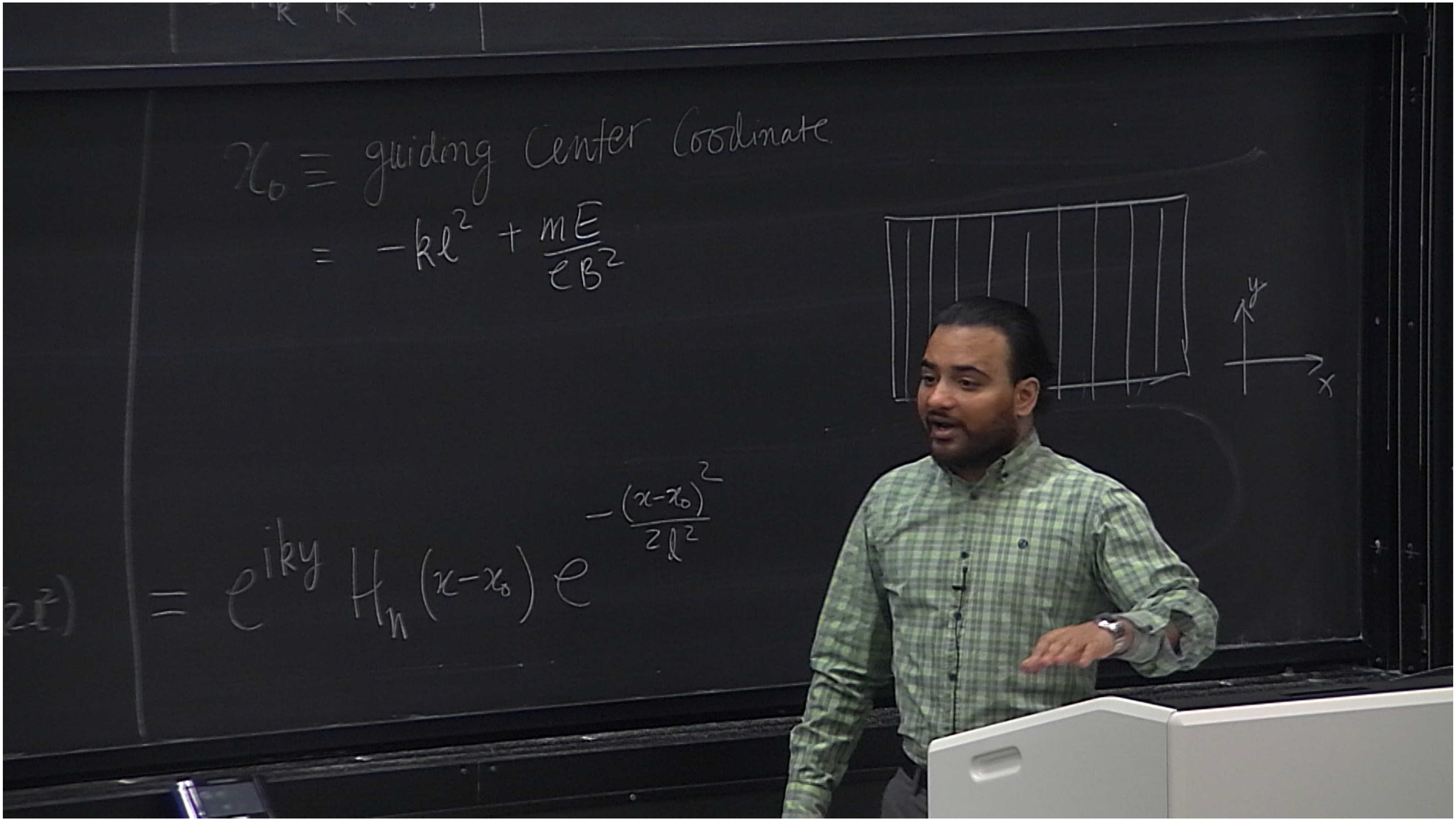
$\downarrow$ Complete the square.

$$E_{n,k} = \hbar\omega_c\left(n+\frac{1}{2}\right) + eE\left(k\ell^2 - \frac{eE}{m\omega_c^2}\right) + \frac{mE^2}{2B^2}$$

$$\psi_{n,k}(x,y) = e^{iky} H_n\left(x + k\ell^2 - \frac{mE}{eB^2}\right) e^{-\left(x+k\ell^2 - \frac{mE}{eB^2}\right)^2/(2\ell^2)}$$


$x_0 \equiv$ guiding Center Coordinate
$= -kl^2 + \frac{mE}{eB^2}$


$x_0 \equiv$ guiding center coordinate
$= -kl^2 + \frac{mE}{eB^2}$
$= e^{iky} H_n(x-x_0)\, e^{-\frac{(x-x_0)^2}{2l^2}}$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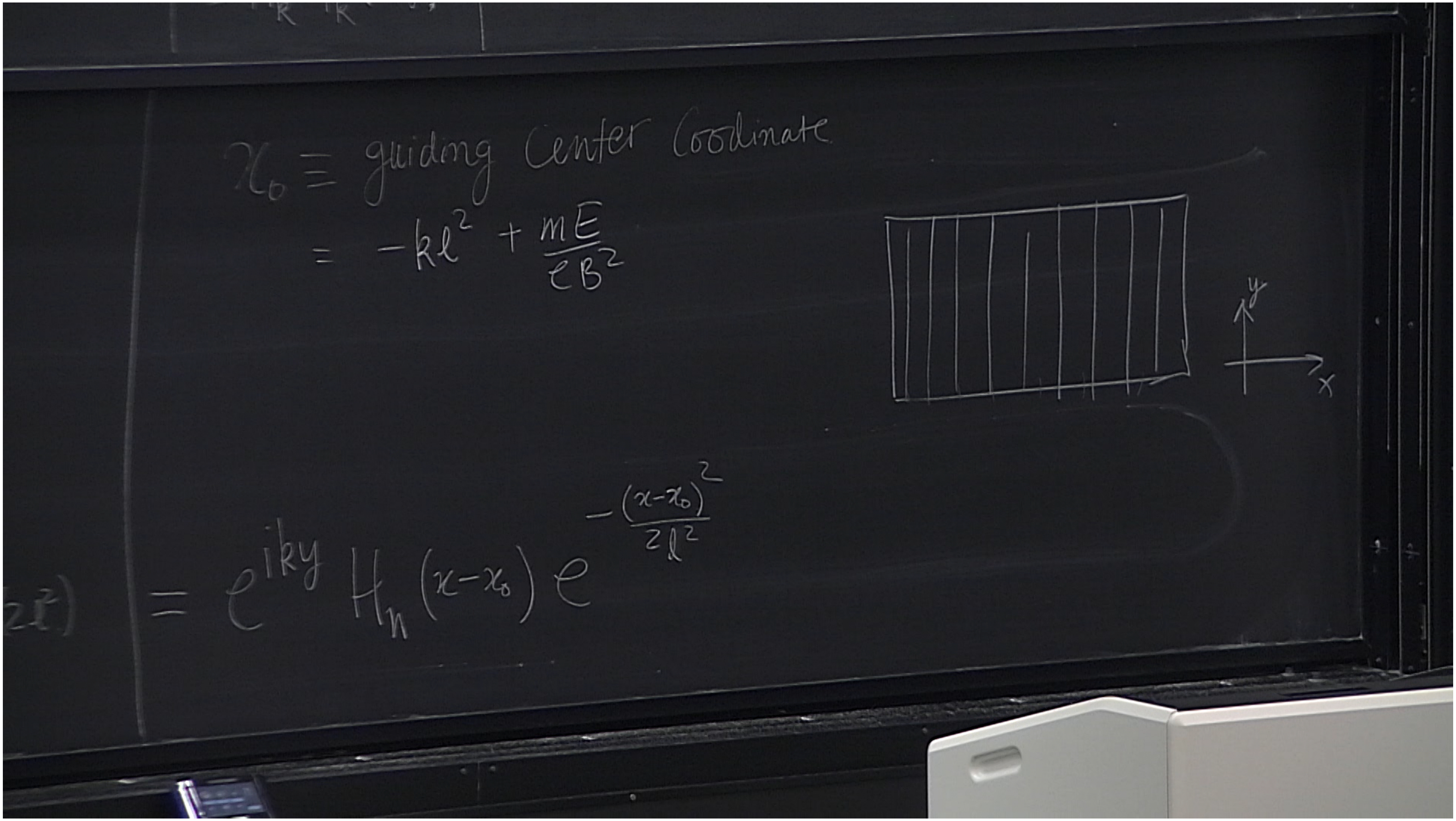
y
x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