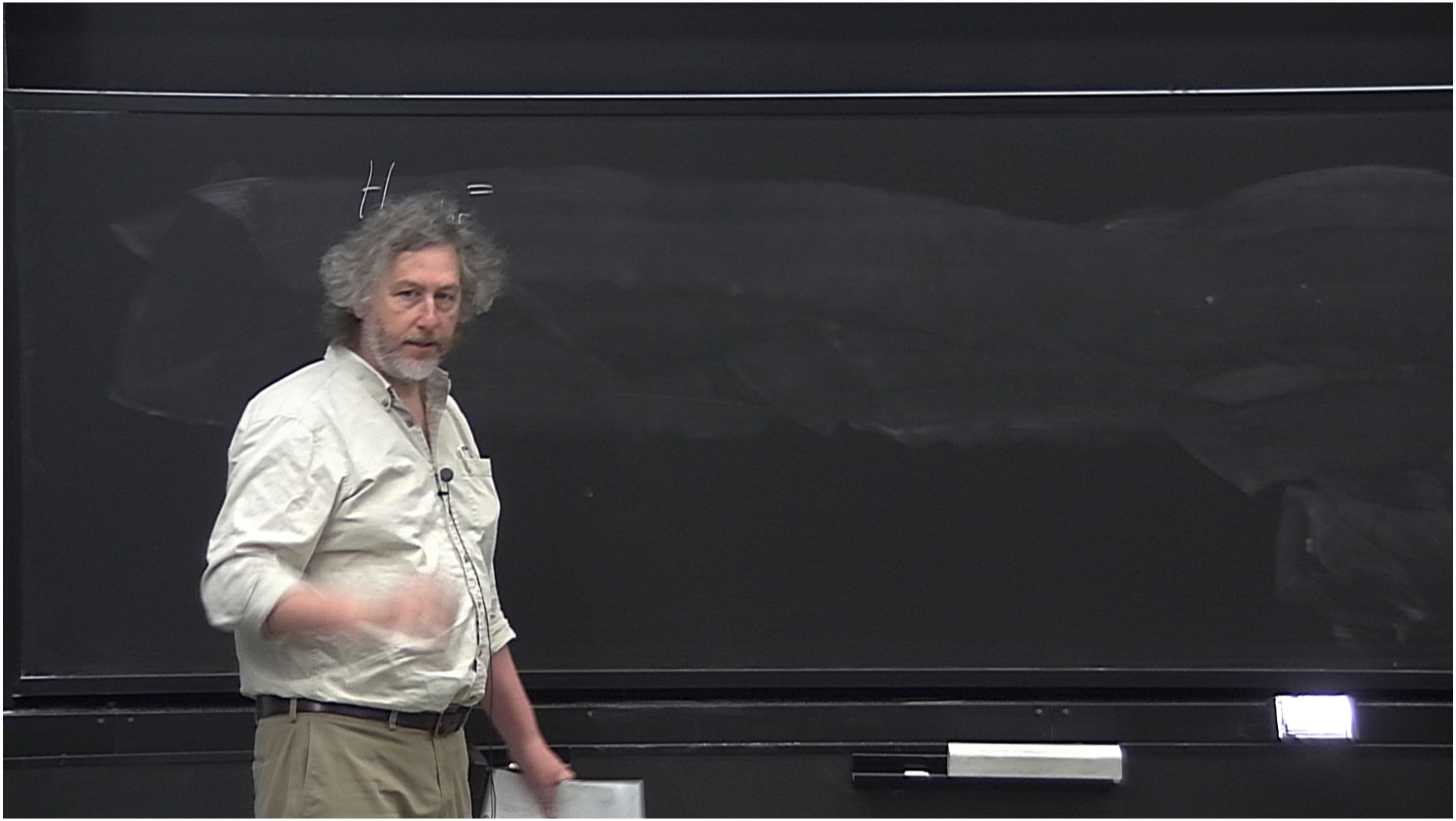
Title: Explorations in Quantum Information - Lecture 11

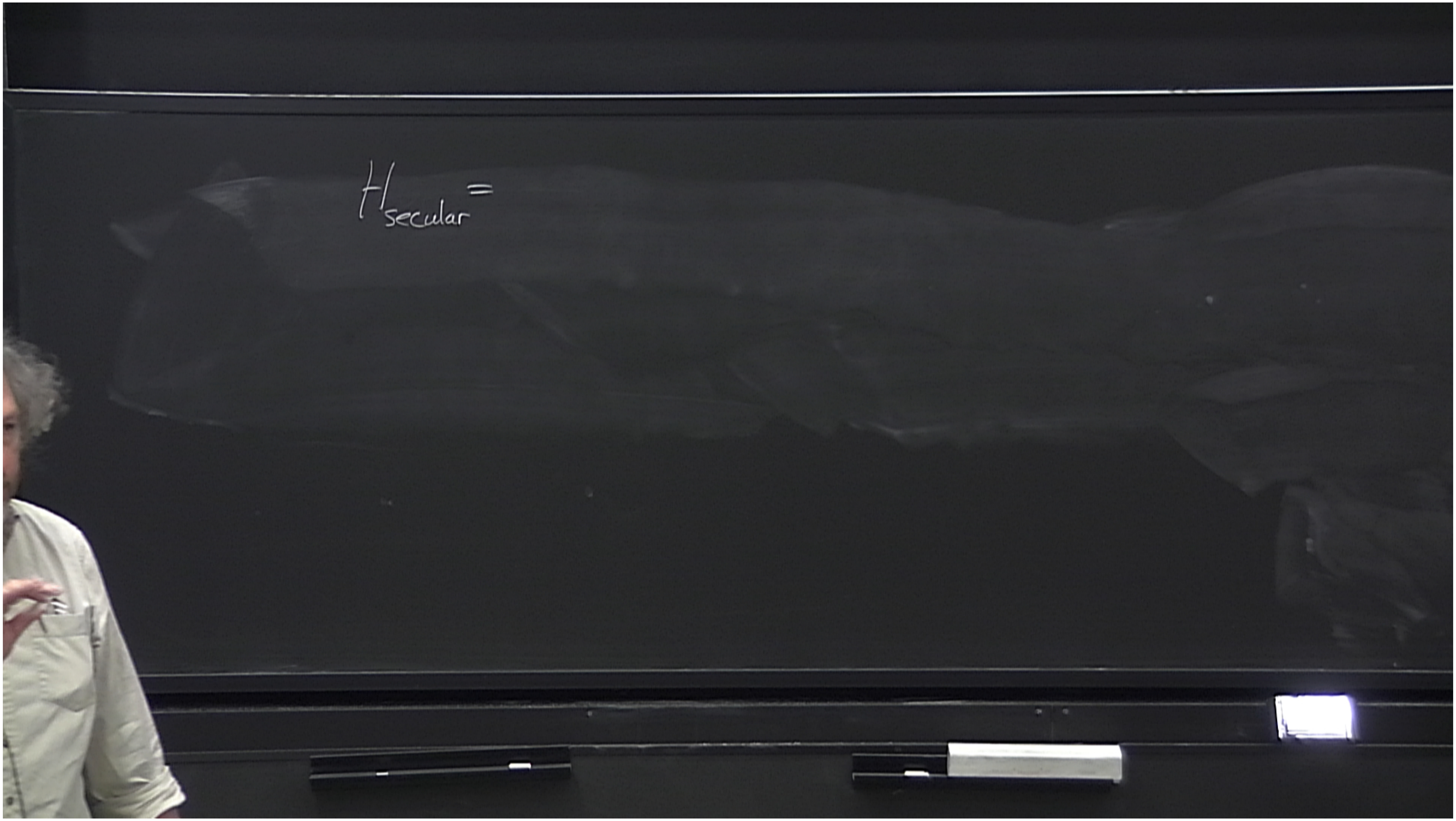
Date: Mar 26, 2012 02:00 PM

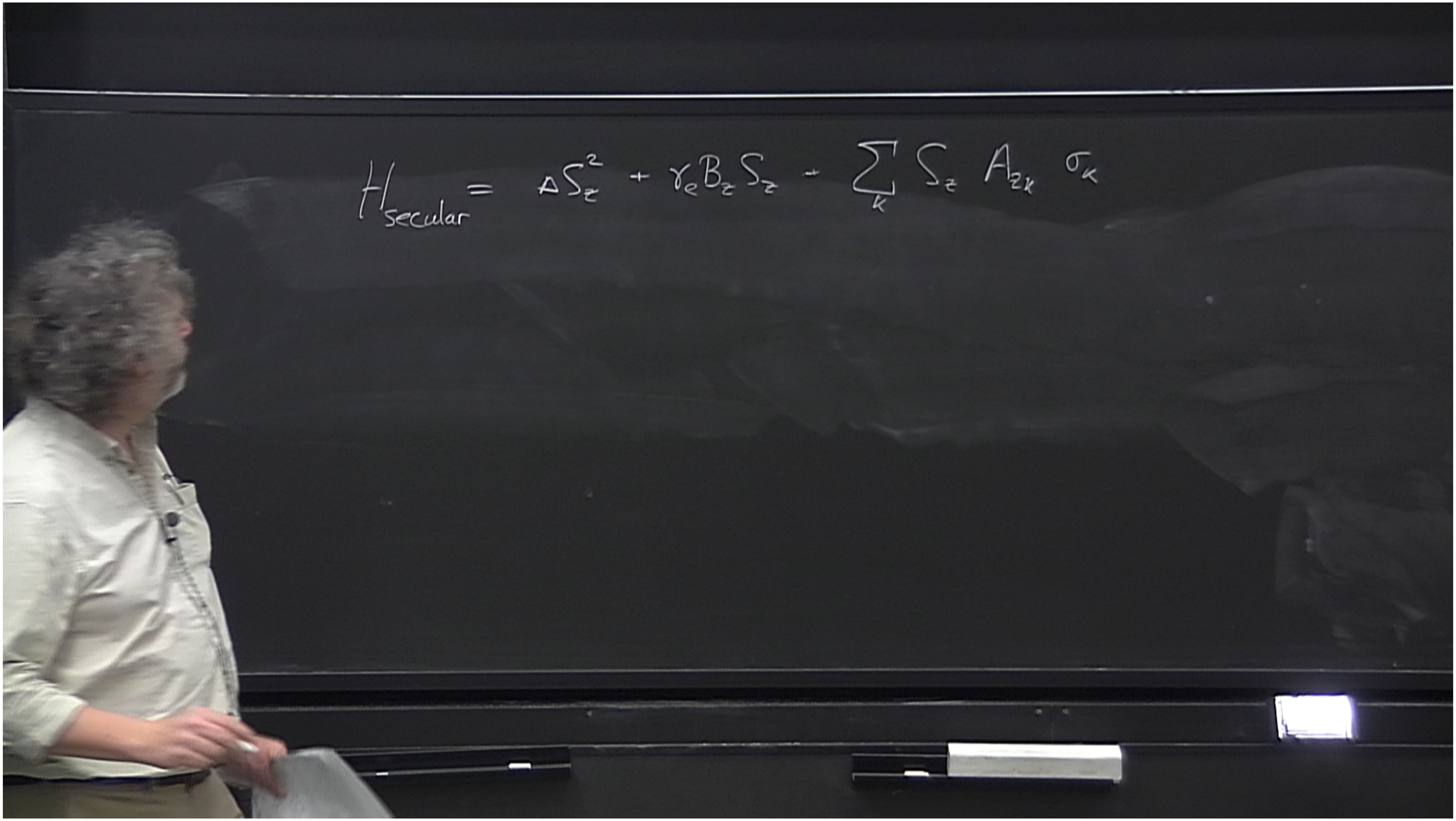
URL: http://pirsa.org/12030018

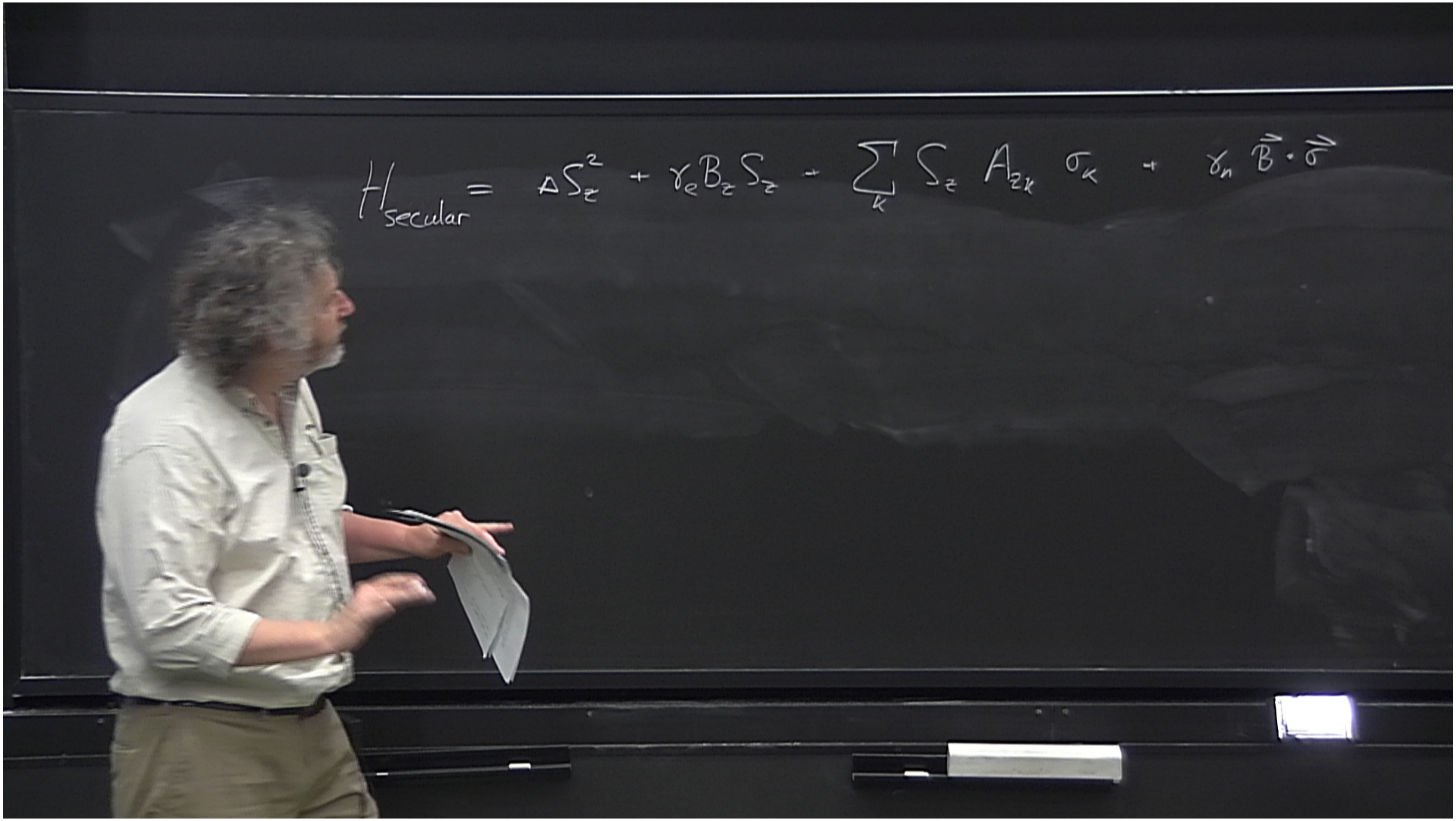
Abstract:



H =


$H_{secular} =$


$H_{secular} = \Delta S_z^2 + \gamma_e B_z S_z - \sum_k S_z A_{zk} \sigma_k$


$H_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \gamma_n \vec{B} \cdot \vec{\sigma}$

$$H_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \gamma_n \vec{B} \cdot \vec{\sigma} + \sum_{j \neq k} \vec{\sigma}^j D \vec{\sigma}^k$$

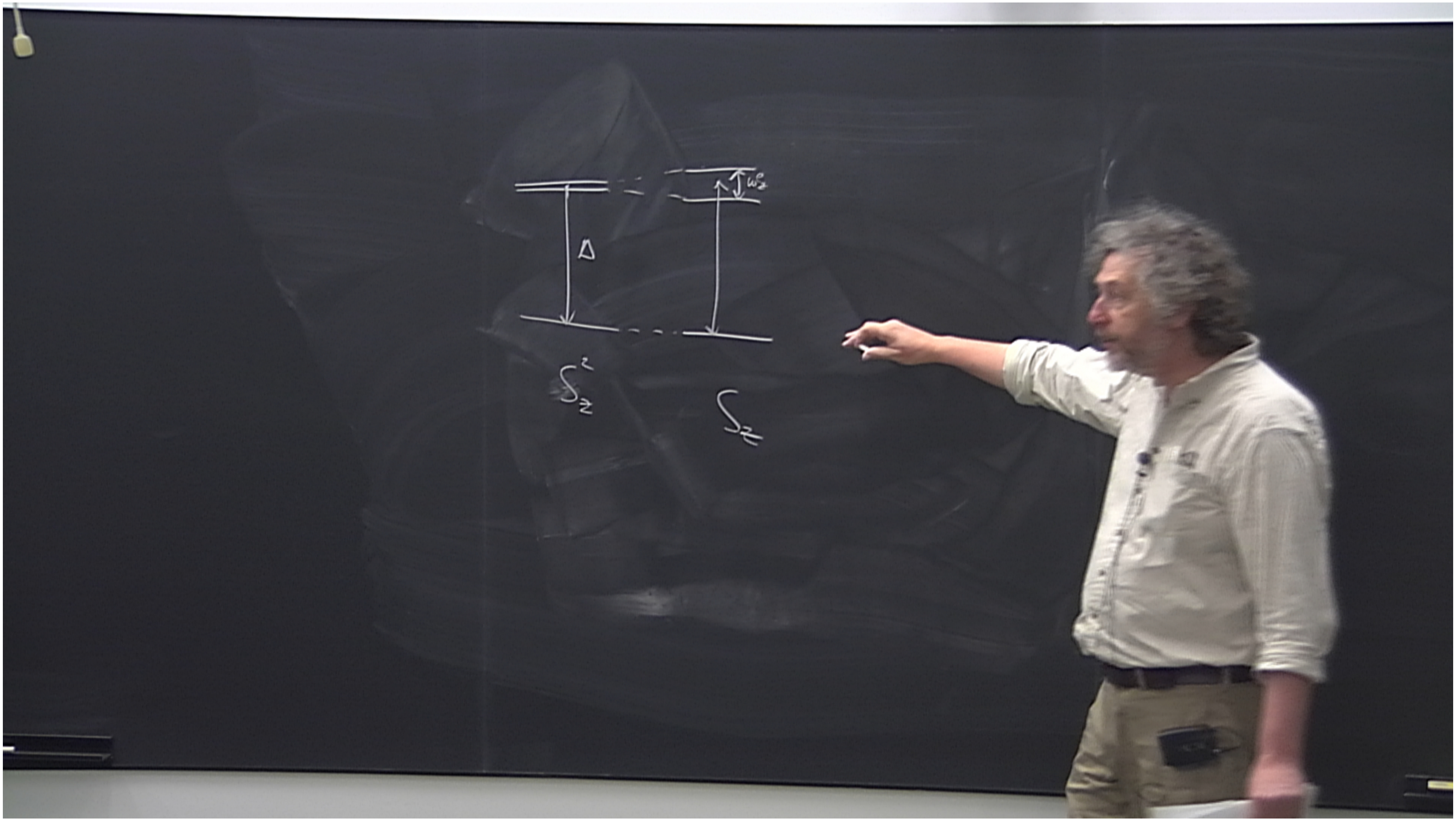
$$H_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \gamma_n \vec{B} \cdot \vec{\sigma} + \sum_{j \neq k} \vec{\sigma}^j D \sigma^k$$

$$\mathcal{H}_{secular} = \Delta S_z^2 + \gamma_e B_z S_z - \sum_k S_z A_{zk} \sigma_k + \gamma_n \vec{B} \cdot \vec{\sigma} + \sum_{j,k} \sigma^j D \sigma^k$$

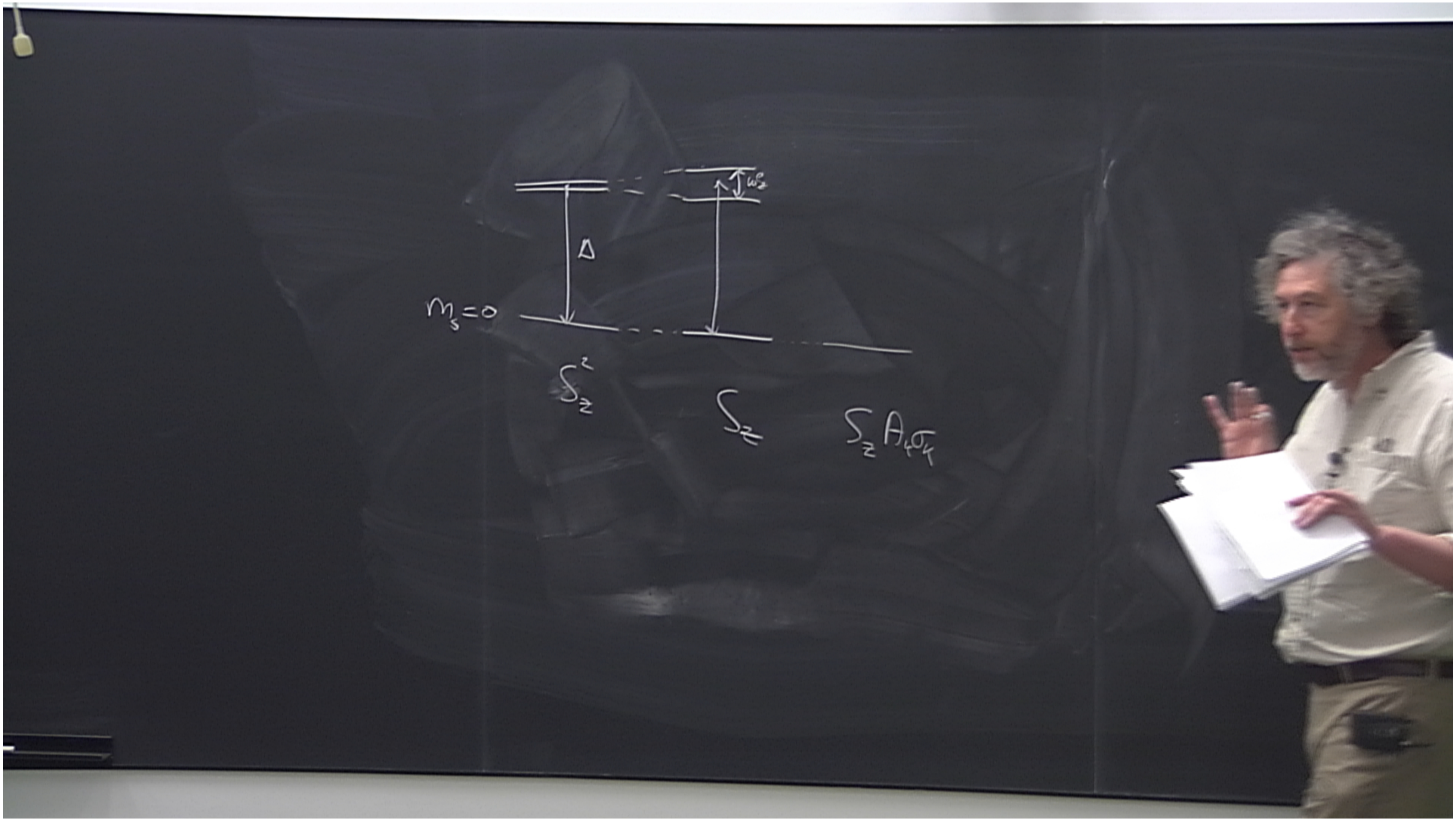
$$\mathcal{H}_{ns} = \gamma (B_x S_x + B_y S_y)$$

$$\mathcal{H}_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \gamma_n \vec{B} \cdot \vec{\sigma} + \sum_{j \neq k} \sigma^j D \sigma^k$$

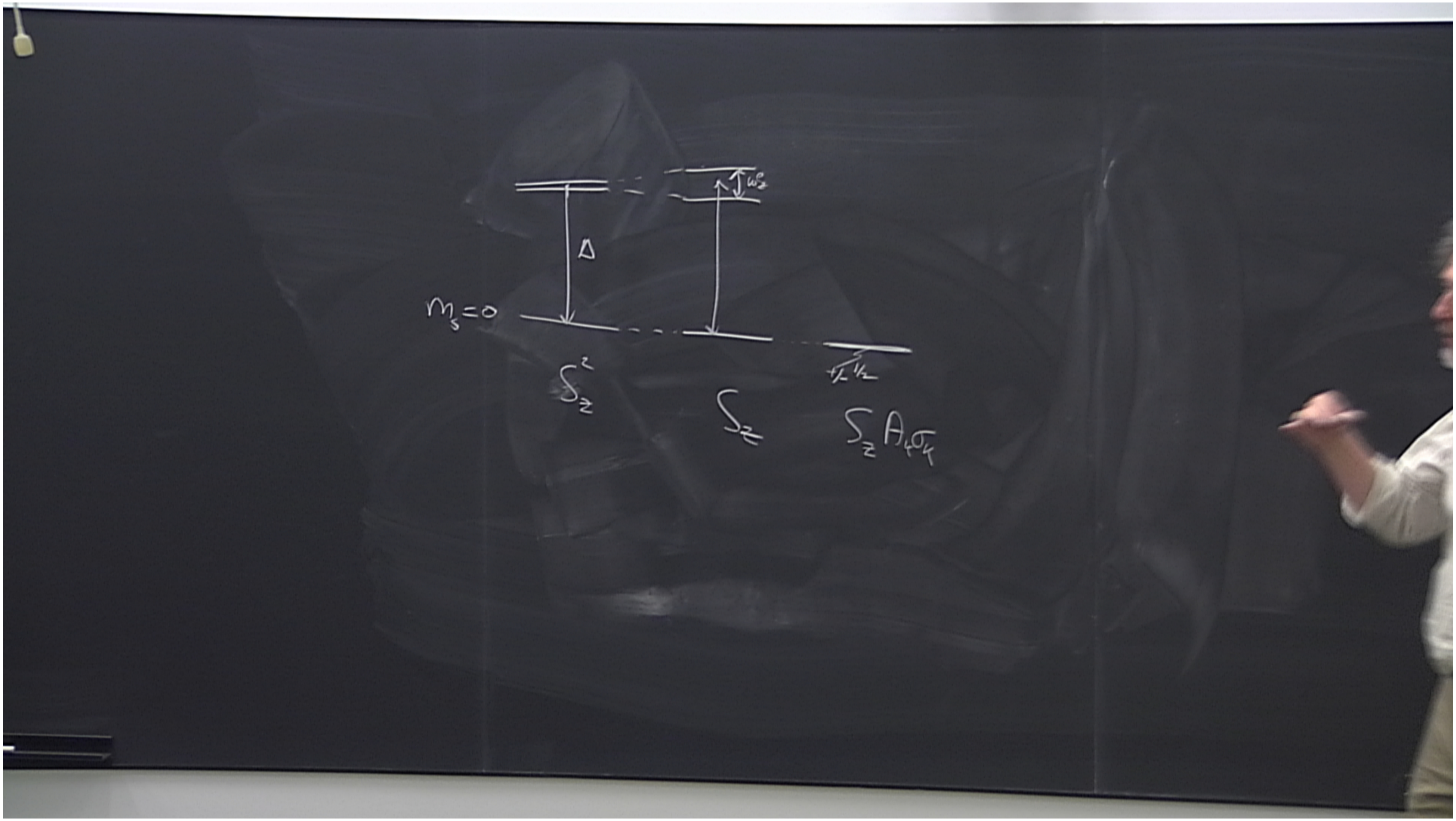
$$\mathcal{H}_{ns} = \gamma_e (B_x S_x + B_y S_y) + \sum_k (S_x A_{xk} \sigma_k + S_y A_{yk} \sigma_k)$$



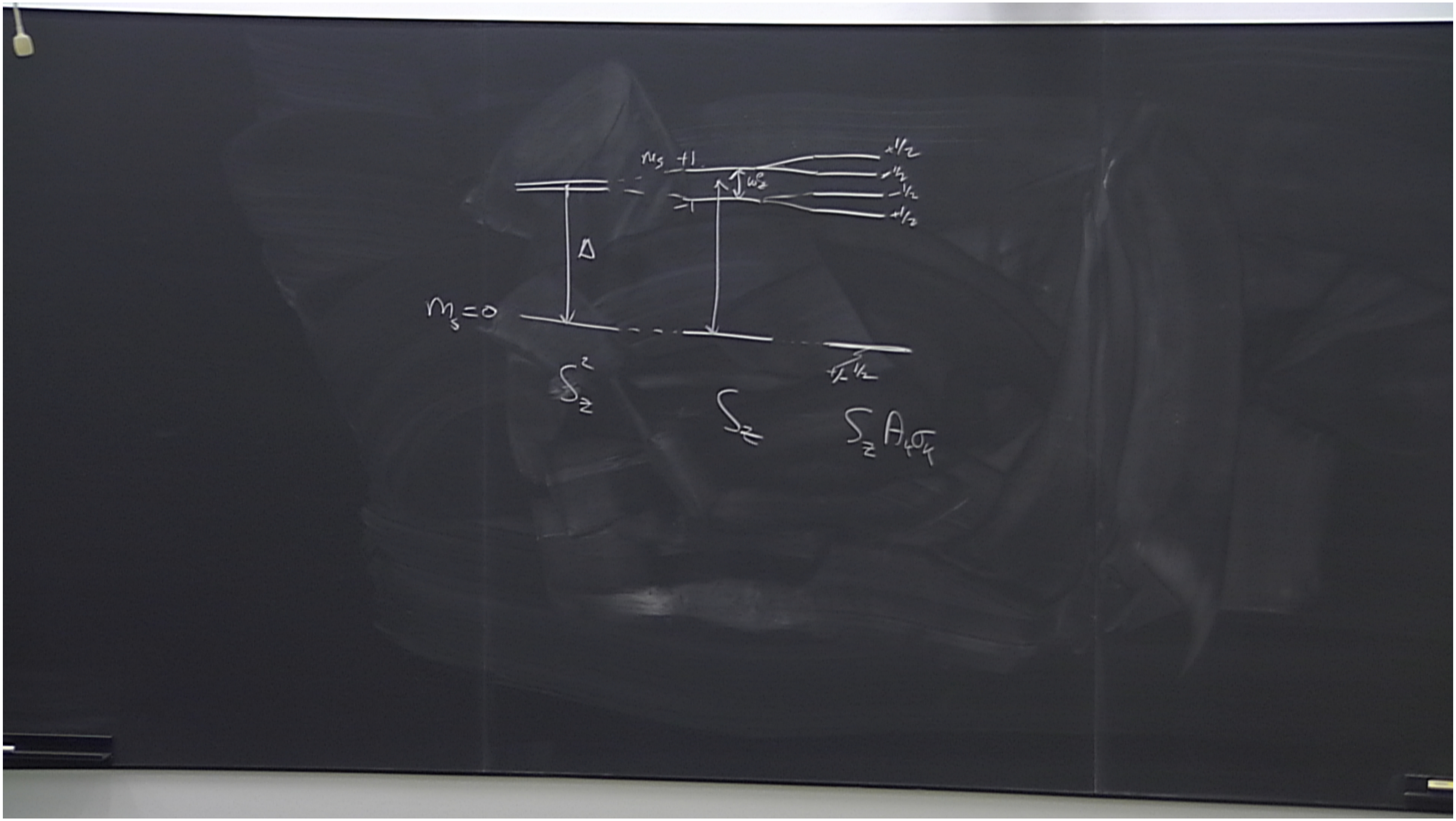
ω_z^e
Δ
S_z^2
S_z

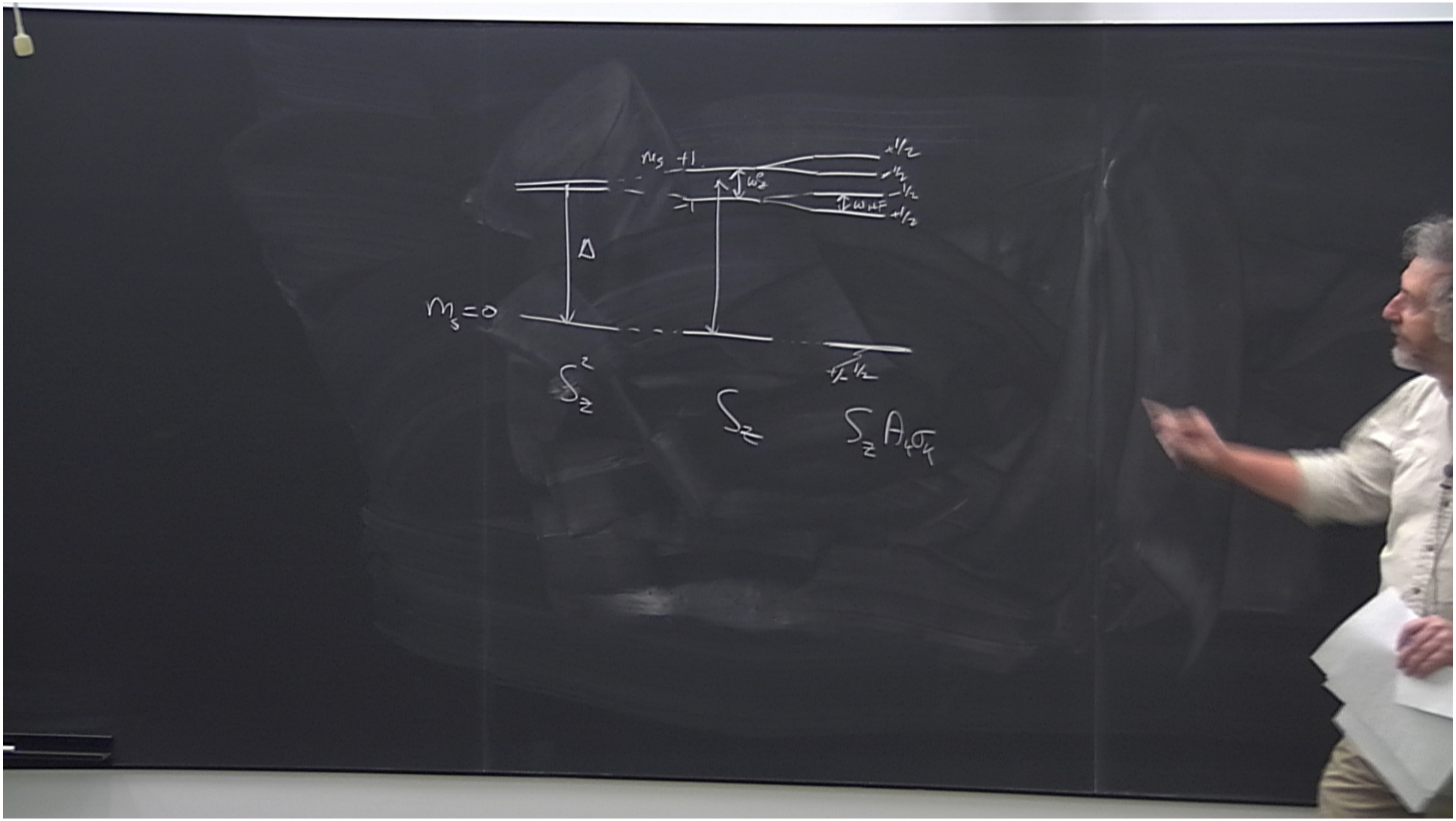


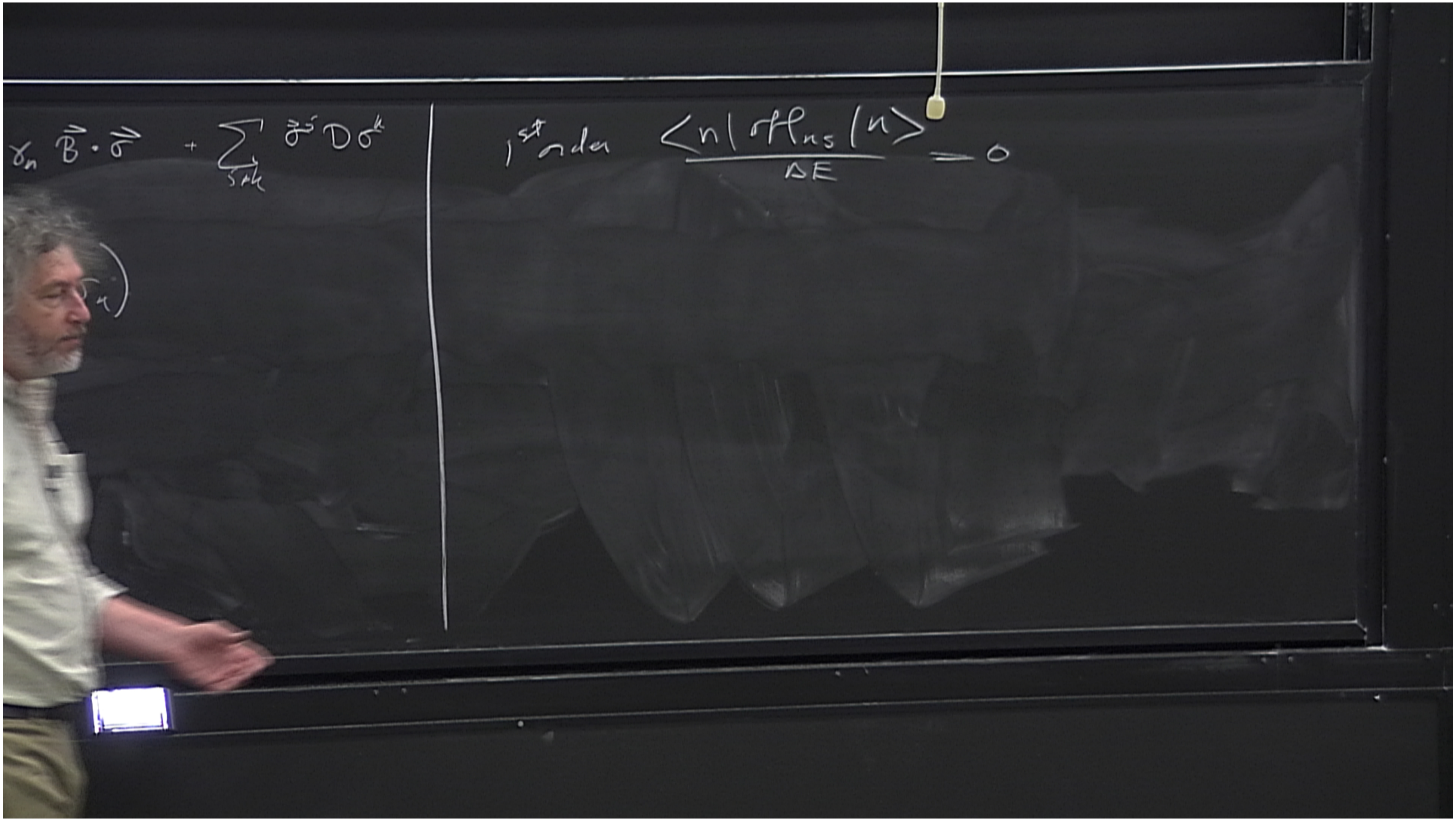
ω_z^e
Δ
$m_s=0$
S_z^2
S_z
$S_z A_k \sigma_k$

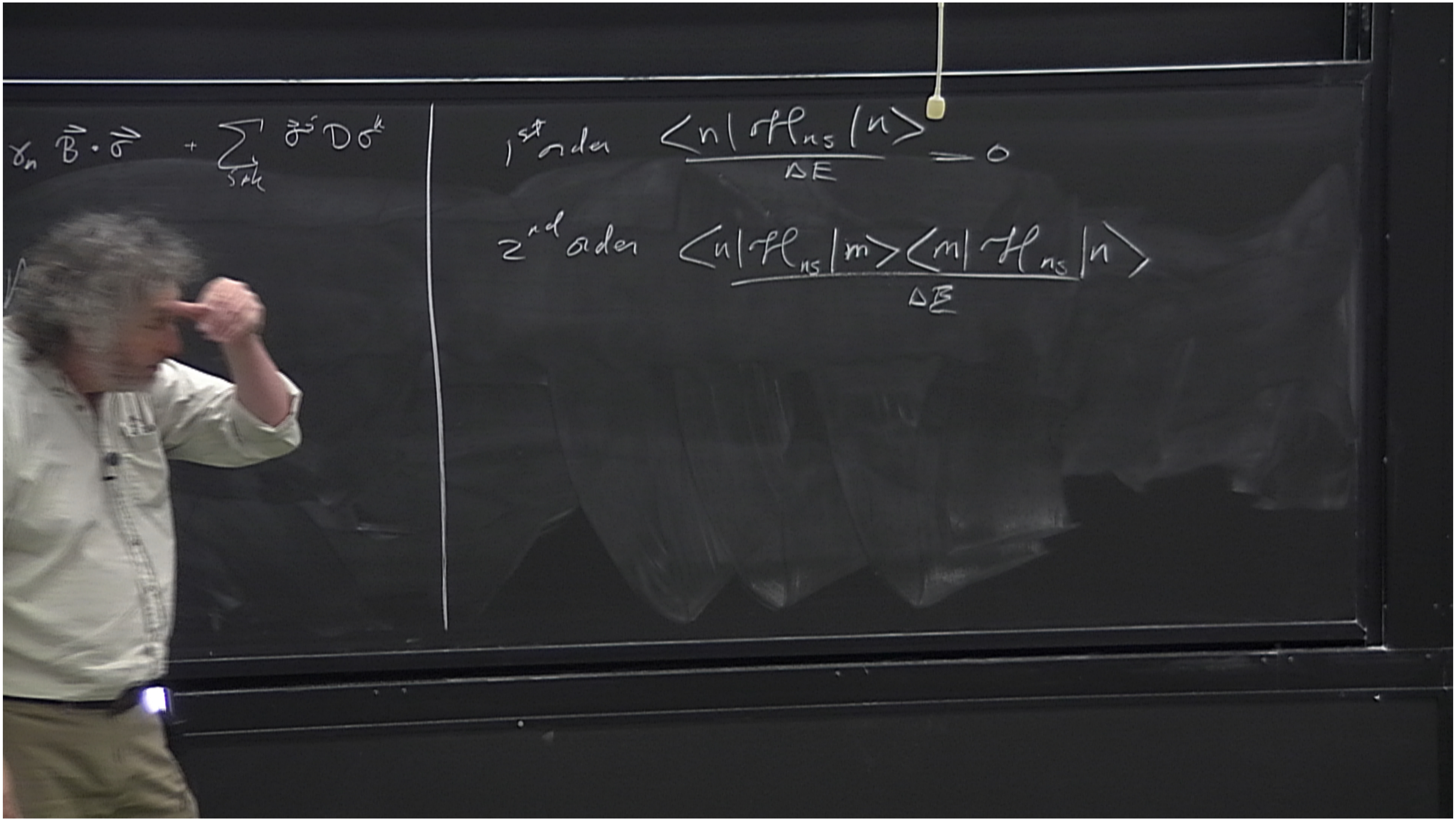


ω_S
Δ
$m_s = 0$
S_z^2
S_z
$S_z A_k \sigma_k$

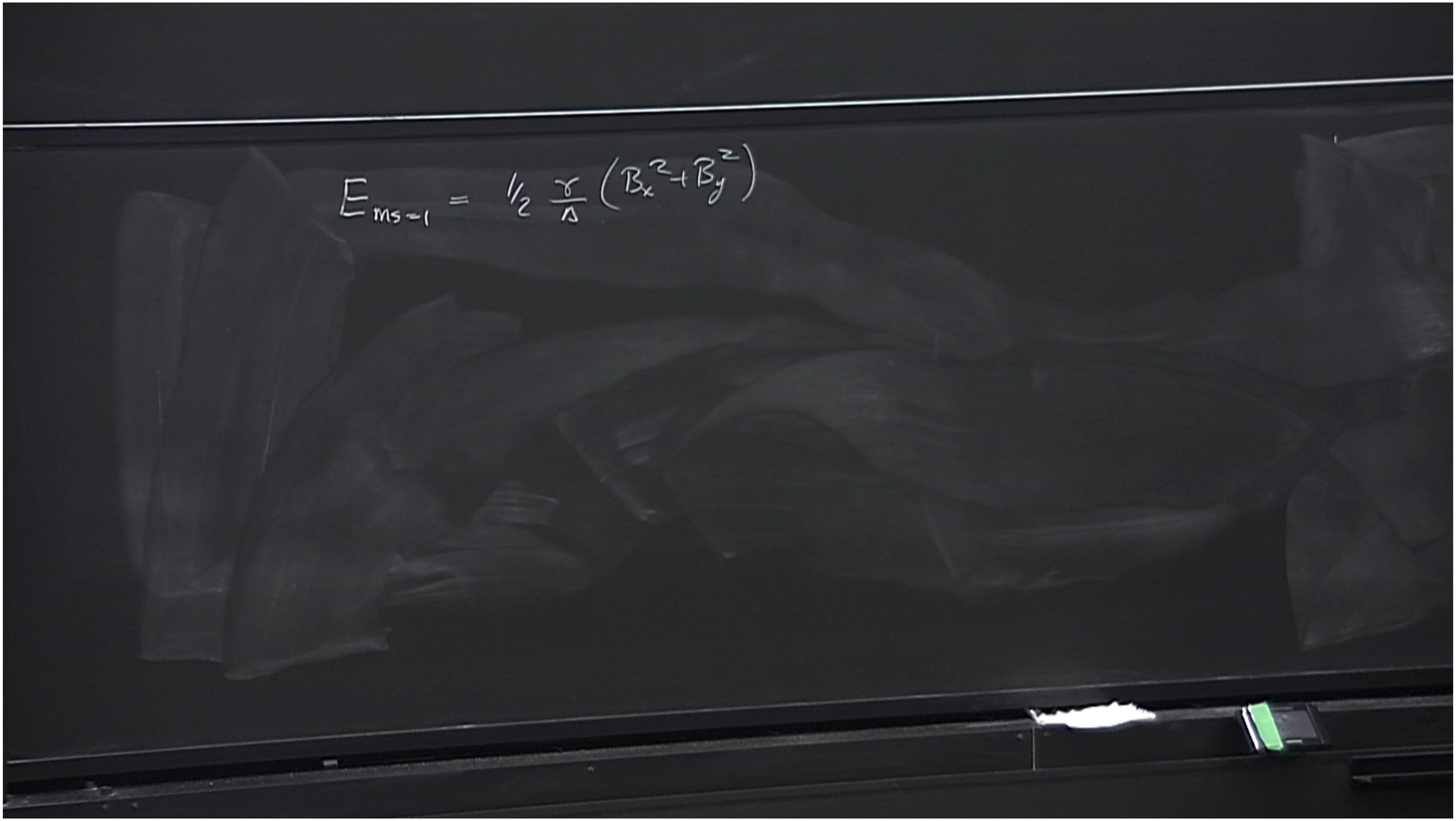

m_s +1
$m_s = 0$
−1
Δ
ω_s
+1/2
−1/2
−1/2
+1/2
+1/2 1/2
S_z^2
S_z
$S_z A_k \sigma_k$


m_s +1
ω_z^e
-1
Δ
$m_s = 0$
ω_{HF}
$+1/2$
$-1/2$
$-1/2$
$+1/2$
S_z^2
S_z
$S_z A_k \sigma_k$


$\gamma_n \vec{B}\cdot\vec{\sigma} + \sum_{j \neq k} \sigma^j D \sigma^k$
1st order $\frac{\langle n | \delta H_{ns} | n \rangle}{\Delta E} = 0$


$\gamma_n \vec{B} \cdot \vec{\sigma} + \sum_{j \neq k} \sigma^j D \sigma^k$
1st order $\frac{\langle n | \mathcal{H}_{ns} | n \rangle}{\Delta E} = 0$
2nd order $\frac{\langle n | \mathcal{H}_{ns} | m \rangle \langle m | \mathcal{H}_{ns} | n \rangle}{\Delta E}$


$E_{m_s=-1} =$


$E_{m_s=-1} = \frac{1}{2} \frac{\gamma}{\Delta} \left(B_x^2 + B_y^2 \right)$

$$E_{m_s=1} = \frac{1}{2}\,\frac{\gamma}{\Delta}\left(B_x^2 + B_y^2\right)$$

$$E_{m_s=0} =$$

$$E_{m_s=1} = \frac{1}{2}\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

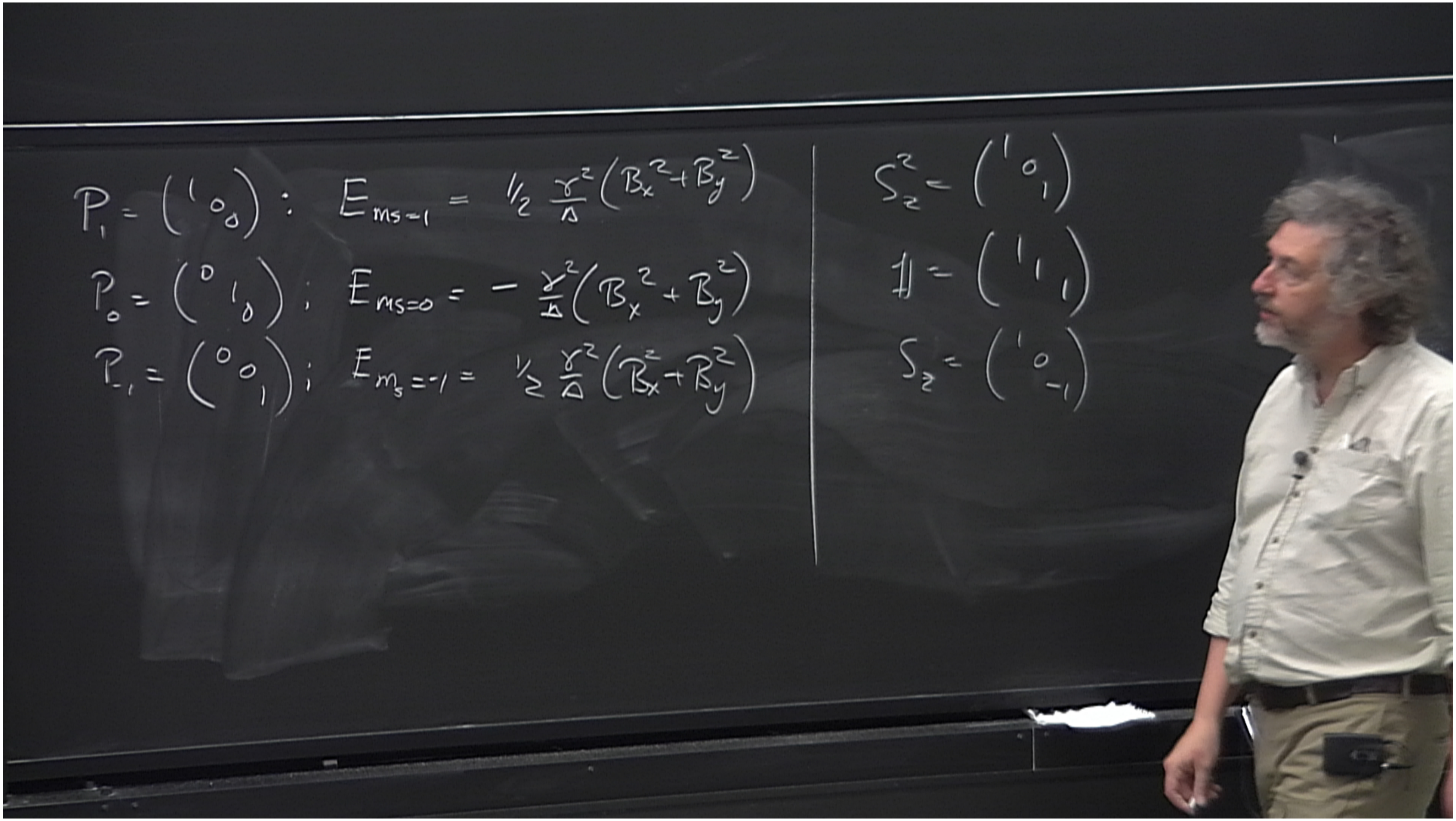
$$E_{m_s=0} = -\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

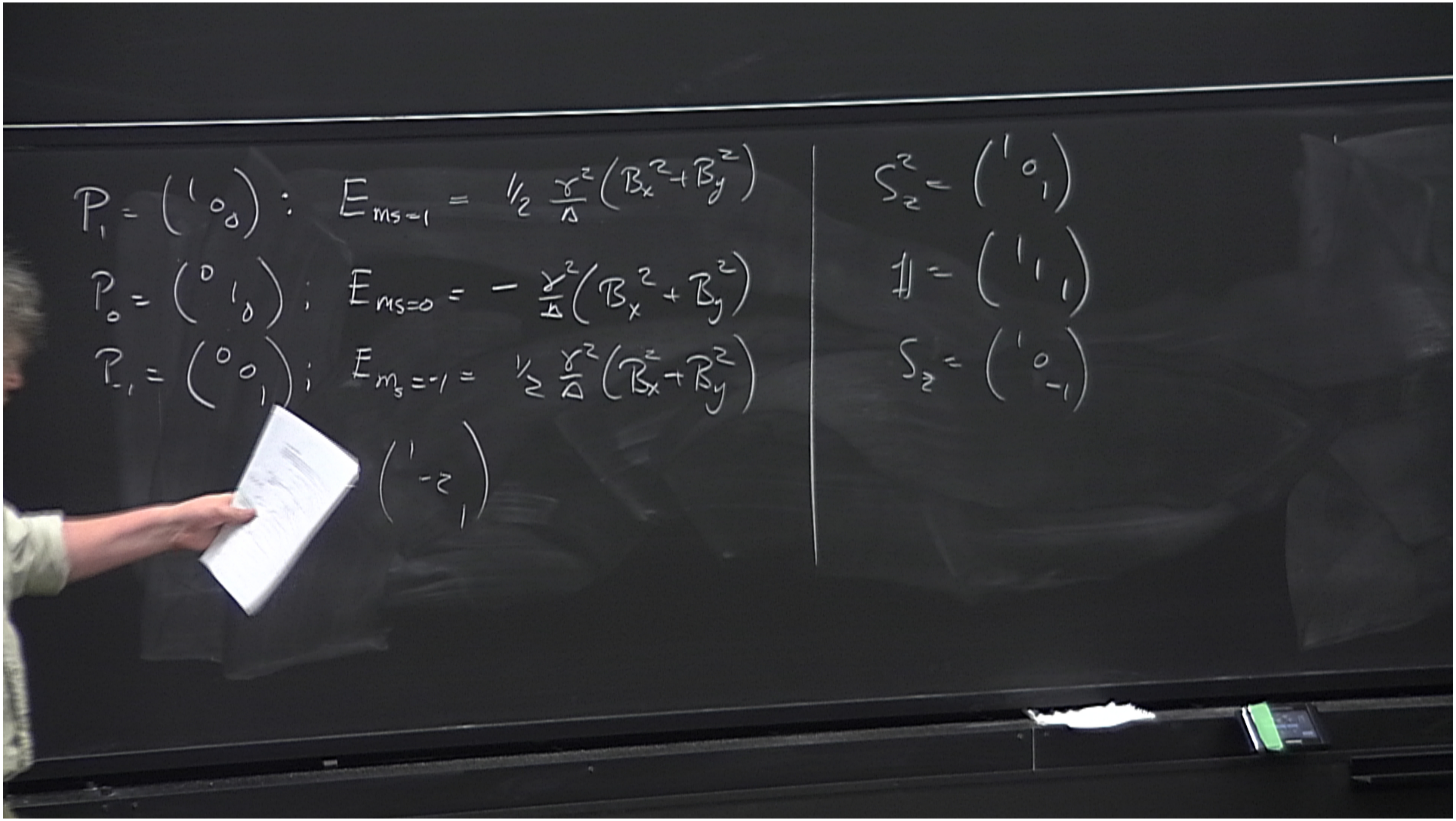
$$E_{m_s=-1} = \frac{1}{2}\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

$$P_1 = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 0 \end{pmatrix} : \quad E_{m_s=1} = \frac{1}{2}\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

$$P_0 = \begin{pmatrix} 0 & & \\ & 1 & \\ & & 0 \end{pmatrix} ; \quad E_{m_s=0} = -\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

$$P_{-1} = \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix} ; \quad E_{m_s=-1} = \frac{1}{2}\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$


$P_1 = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 0 \end{pmatrix}: \quad E_{m_s=1} = \frac{1}{2}\frac{\gamma^2}{\Delta}(B_x^2 + B_y^2)$
$P_0 = \begin{pmatrix} 0 & & \\ & 1 & \\ & & 0 \end{pmatrix}; \quad E_{m_s=0} = -\frac{\gamma^2}{\Delta}(B_x^2 + B_y^2)$
$P_{-1} = \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix}; \quad E_{m_s=-1} = \frac{1}{2}\frac{\gamma^2}{\Delta}(B_x^2 + B_y^2)$
$S_z^2 = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 1 \end{pmatrix}$
$\mathbb{1} = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$
$S_z = \begin{pmatrix} 1 & & \\ & 0 & \\ & & -1 \end{pmatrix}$



$P_1 = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 0 \end{pmatrix}$: $E_{m_s=1} = \frac{1}{2}\frac{\gamma^2}{\Delta}(B_x^2 + B_y^2)$
$P_0 = \begin{pmatrix} 0 & & \\ & 1 & \\ & & 0 \end{pmatrix}$; $E_{m_s=0} = -\frac{\gamma^2}{\Delta}(B_x^2 + B_y^2)$
$P_{-1} = \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix}$; $E_{m_s=-1} = \frac{1}{2}\frac{\gamma^2}{\Delta}(B_x^2 + B_y^2)$
$\begin{pmatrix} 1 & & \\ & -2 & \\ & & 1 \end{pmatrix}$
$S_z^2 = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 1 \end{pmatrix}$
$\mathbb{1} = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$
$S_z = \begin{pmatrix} 1 & & \\ & 0 & \\ & & -1 \end{pmatrix}$

$$P_1 = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 0 \end{pmatrix} : \quad E_{m_s=1} = \frac{1}{2}\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

$$P_0 = \begin{pmatrix} 0 & & \\ & 1 & \\ & & 0 \end{pmatrix} ; \quad E_{m_s=0} = -\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

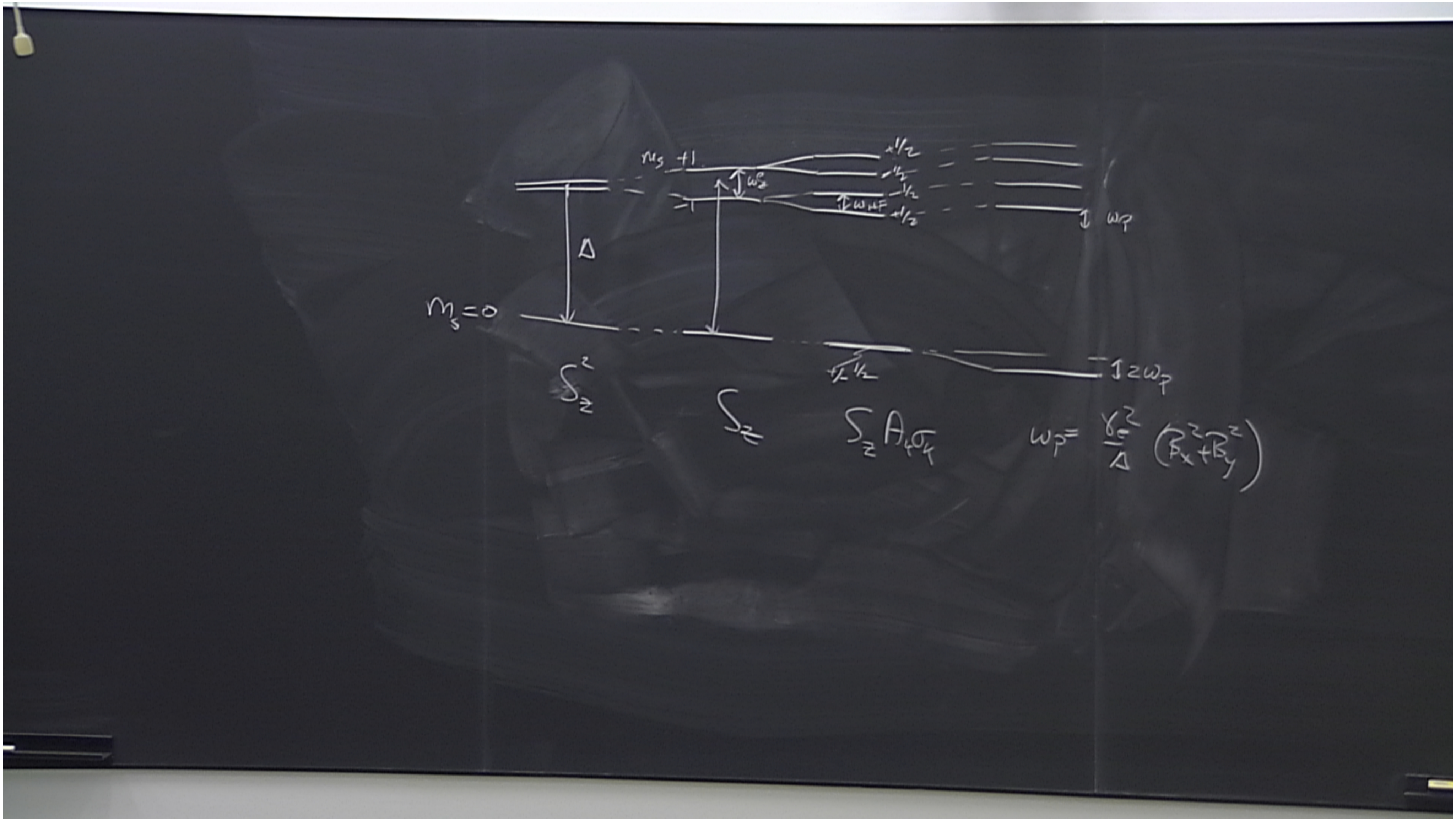
$$P_{-1} = \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix} ; \quad E_{m_s=-1} = \frac{1}{2}\frac{\gamma^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

$$= \begin{pmatrix} 1 & & \\ & -2 & \\ & & 1 \end{pmatrix} = \left(3S_z^2 - 2\mathbb{1}\right)$$

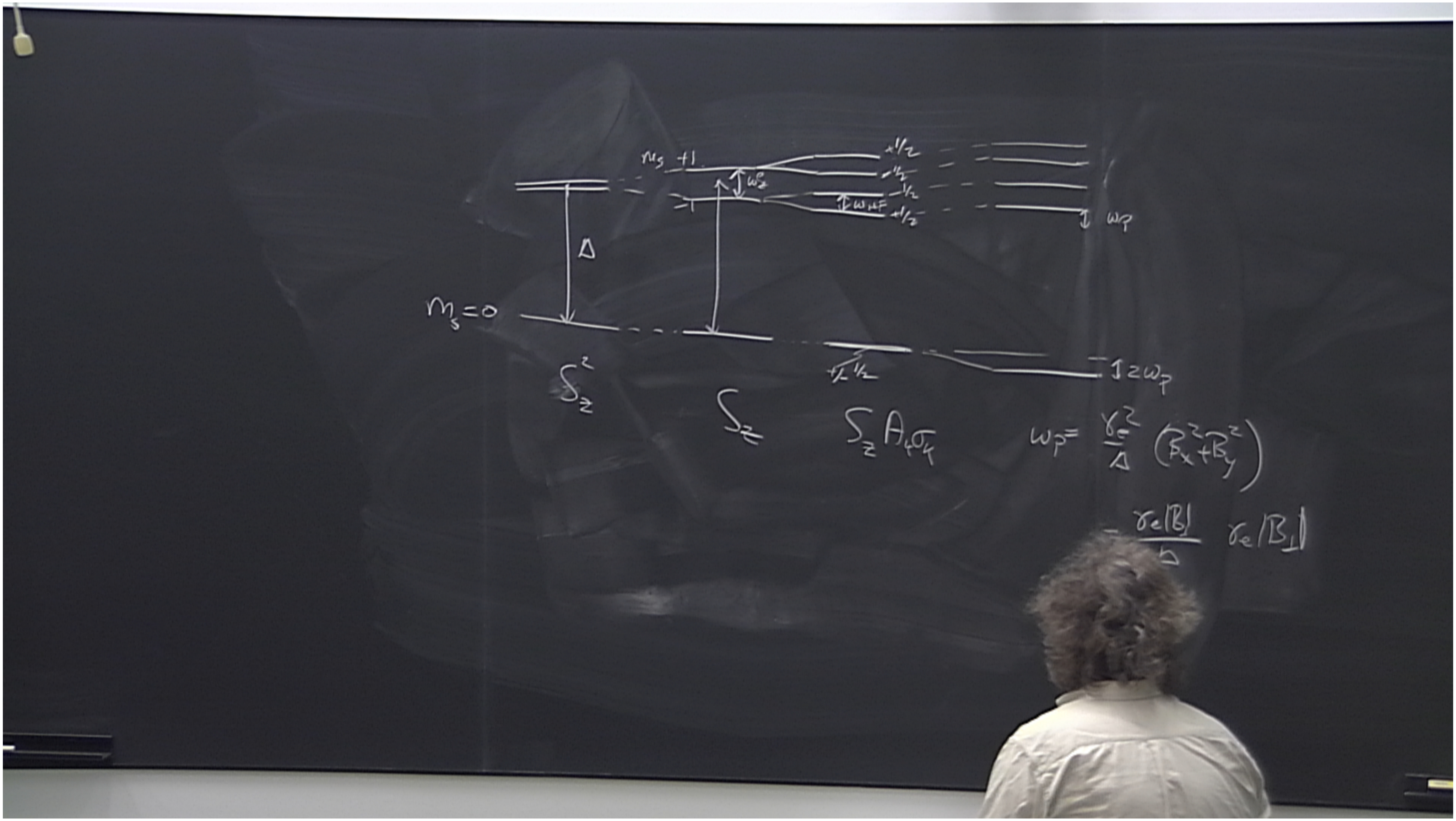
$$S_z^2 = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 1 \end{pmatrix}$$

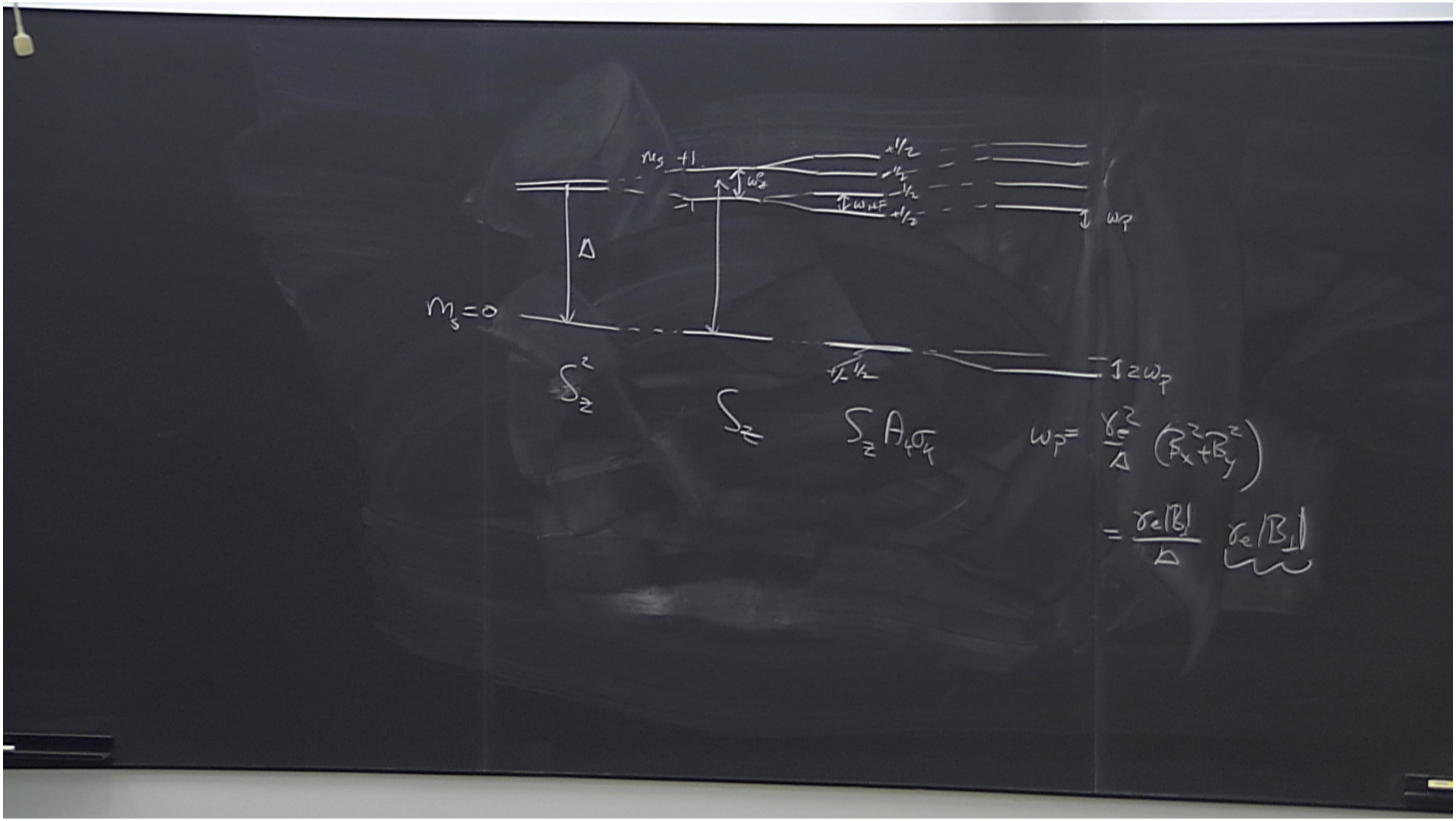
$$\mathbb{1} = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$$

$$S_z = \begin{pmatrix} 1 & & \\ & 0 & \\ & & -1 \end{pmatrix}$$



m_s +1
ω_z
-1
$+1/2$
$-1/2$
$-1/2$
$+1/2$
ω_{HF}
ω_p
Δ
$m_s = 0$
$+1/2$ $-1/2$
$2\omega_p$
S_z^2
S_z
$S_z A_i \sigma_i$
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2 + B_y^2)$

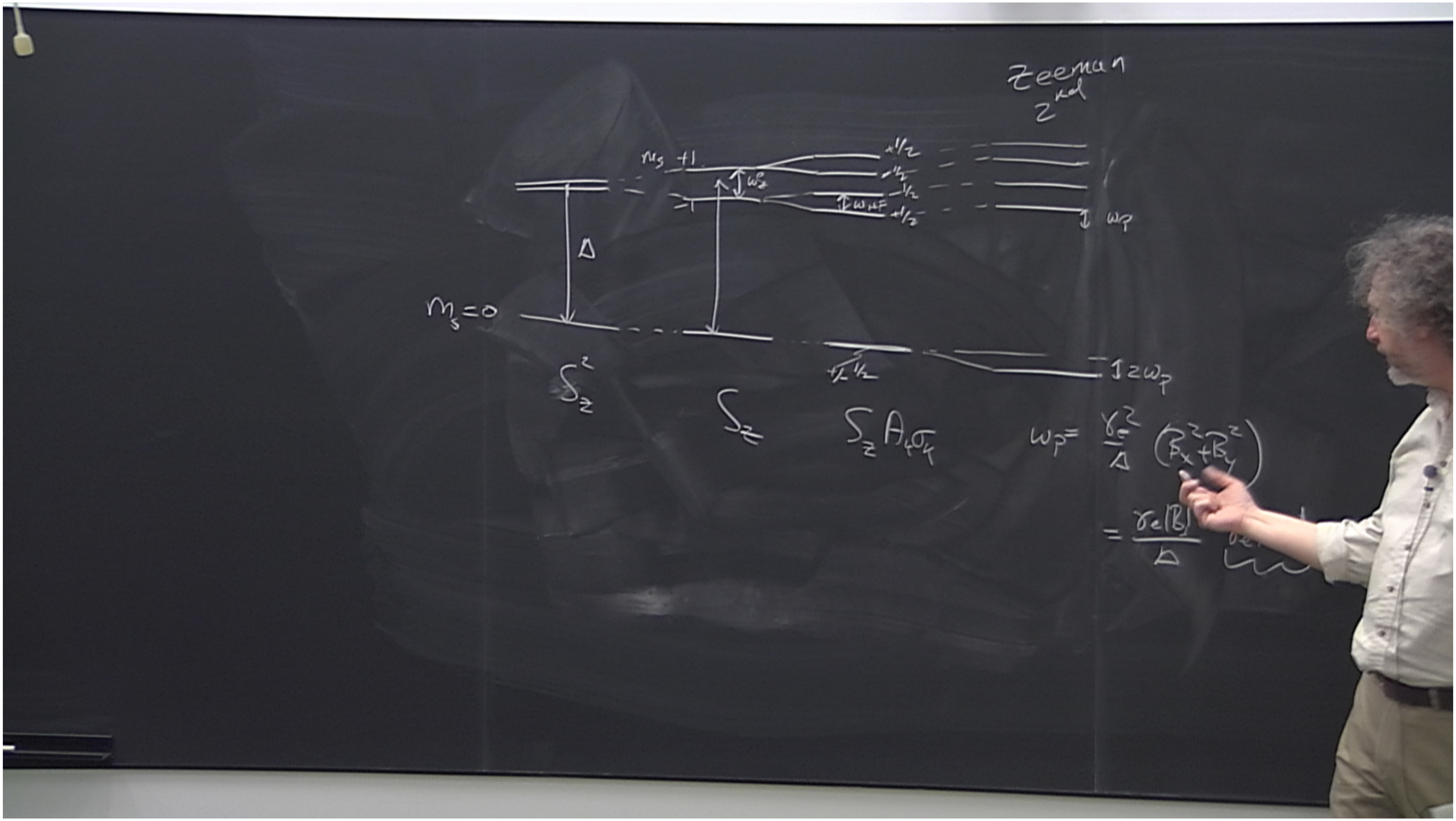

m_s +1
-1
Δ
m_s = 0
ω_HF
ω_P
2ω_P
S_z^2
S_z
S_z A_k σ_k
ω_P = γ_e^2/Δ (B_x^2 + B_y^2)
γ_e|B_⊥|

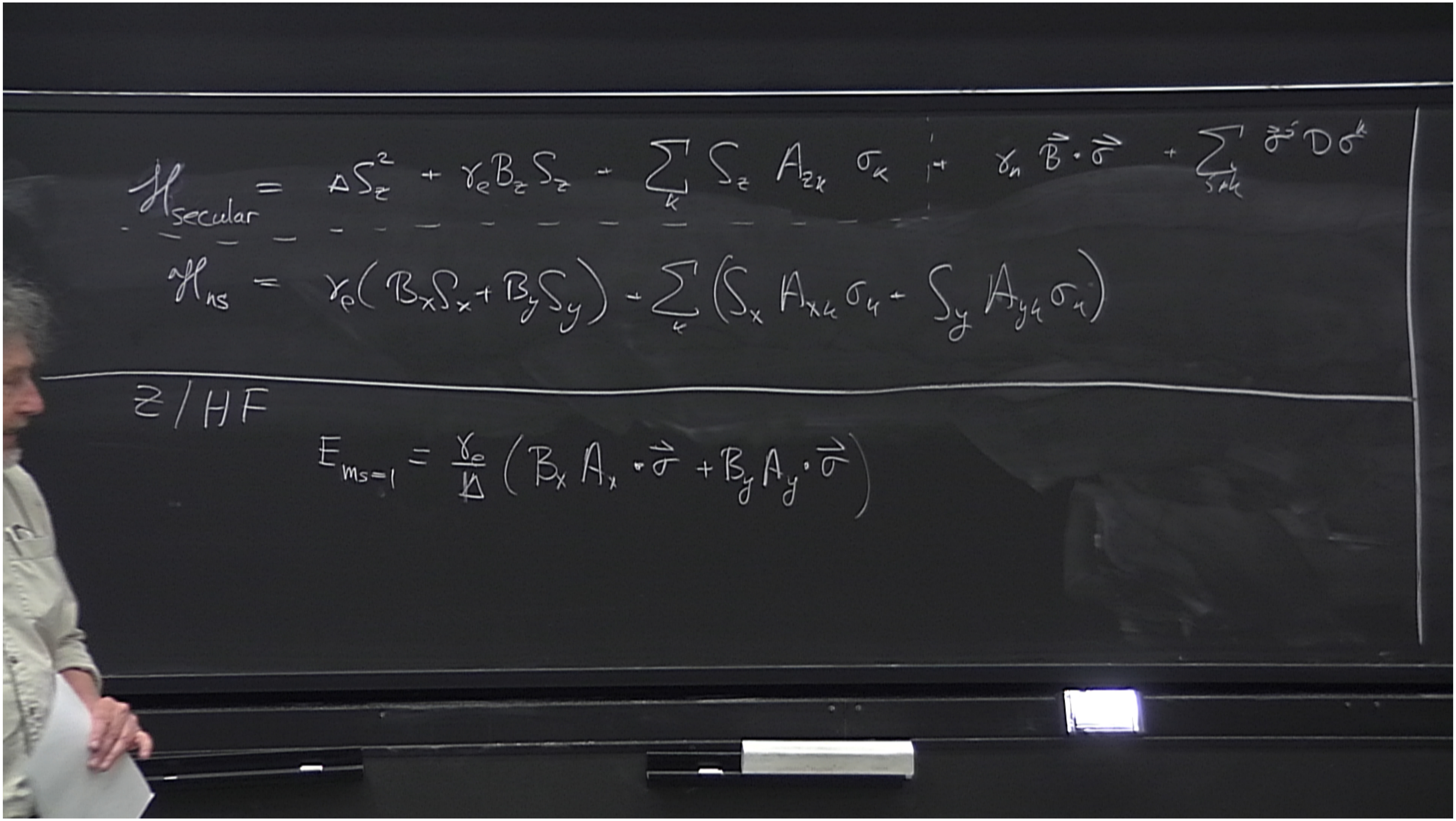

m_s +1
-1
+1/2
-1/2
-1/2
+1/2
ω_s
ω_HF
ω_p
Δ
m_s = 0
+1/2 -1/2
2ω_p
S_z^2
S_z
S_z A_y σ_y
ω_p = γ_e^2/Δ (B_x^2 + B_y^2)
= γ_e|B|/Δ γ_e|B_⊥|

$$\mathcal{H}_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \gamma_n \vec{B} \cdot \vec{\sigma} + \sum$$

$$\mathcal{H}_{ns} = \gamma_e (B_x S_x + B_y S_y) + \sum_k (S_x A_{xk} \sigma_k + S_y A_{yk} \sigma_k)$$

Z / HF


Zeeman
2nd
m_s +1
+1/2
-1/2
-1/2
+1/2
ω_s
ω_{HF}
-1
ω_p
Δ
$m_s=0$
$2\omega_p$
S_z^2
S_z
$S_z A_\perp \sigma_\perp$
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2+B_y^2)$
$= \frac{\gamma_e |B|}{\Delta}$


$\mathcal{H}_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \gamma_n \vec{B} \cdot \vec{\sigma} + \sum_{j \neq k} \vec{\sigma}^j D \sigma^k$
$\mathcal{H}_{ns} = \gamma_e (B_x S_x + B_y S_y) + \sum_k (S_x A_{xk} \sigma_k + S_y A_{yk} \sigma_k)$
Z/HF
$E_{ms=1} = \frac{\gamma_e}{\Delta} (B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma})$

$$\mathcal{H}_{ns} = \gamma_e \left(B_x S_x + B_y S_y \right) + \sum_k \left(S_x A_{xk} \sigma_k + S_y A_{yk} \sigma_k \right)$$

Z/HF

$$E_{m_s = 1} = \frac{\gamma_e}{\Delta} \left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma} \right)$$

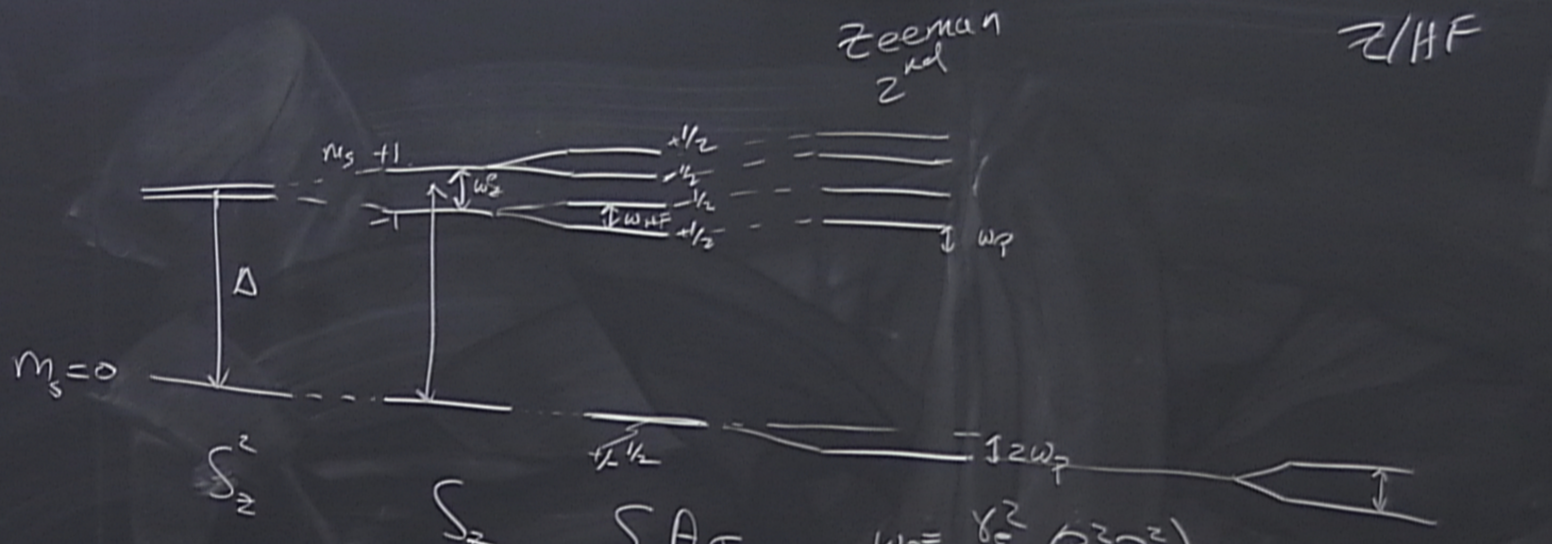
$$\mathcal{H}^{(2)}_{Z/HF} = \left(3 S_z^2 - 2 \mathbb{1} \right) \frac{\gamma_e}{\Delta} \left(B_x A_x + B_y A_y \right) \sigma$$

$$\mathcal{H}_{ns} = \gamma_e(B_x S_x + B_y S_y) + \sum_k (S_x A_{xk}\sigma_k + S_y A_{yk}\sigma_k)$$

Z/HF

$$E_{m_s=1} = \frac{\gamma_e}{\Delta}\left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma}\right)$$

$$\mathcal{H}^{(2)}_{Z/HF} = (3S_z^2 - 2\mathbb{1})\frac{\gamma_e}{\Delta}(B_x A_x + B_y A_y)\vec{\sigma}$$



S_z^2 $\quad S_z \quad S_z A_y \sigma_y$

$$\omega_p = \frac{\gamma_e^2}{\Delta}\left(B_x^2 + B_y^2\right)$$

$$= \frac{\gamma_e |B|}{\Delta} \quad \gamma_e |B_\perp|$$

$$\frac{\gamma_e B_\perp}{\Delta} \quad A_\perp$$

$$\mathcal{H}_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \underbrace{\gamma_n \vec{B} \cdot \vec{\sigma}}_{\sim 10\,kHz} + \sum_{j \neq k} \sigma^j D \sigma^k$$

$$\mathcal{H}_{ns} = \gamma_e (B_x S_x + B_y S_y) + \sum_k (S_x A_{xk} \sigma_k + S_y A_{yk} \sigma_k)$$

Z / HF

$$E_{m_s=1} = \frac{\gamma_e}{\Delta} (B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma})$$

$$\mathcal{H}^{(2)}_{Z/HF} = (3 S_z^2 - 2 \mathbb{1}) \frac{\gamma_e}{\Delta} (B_x A_x + B_y A_y) \vec{\sigma}$$

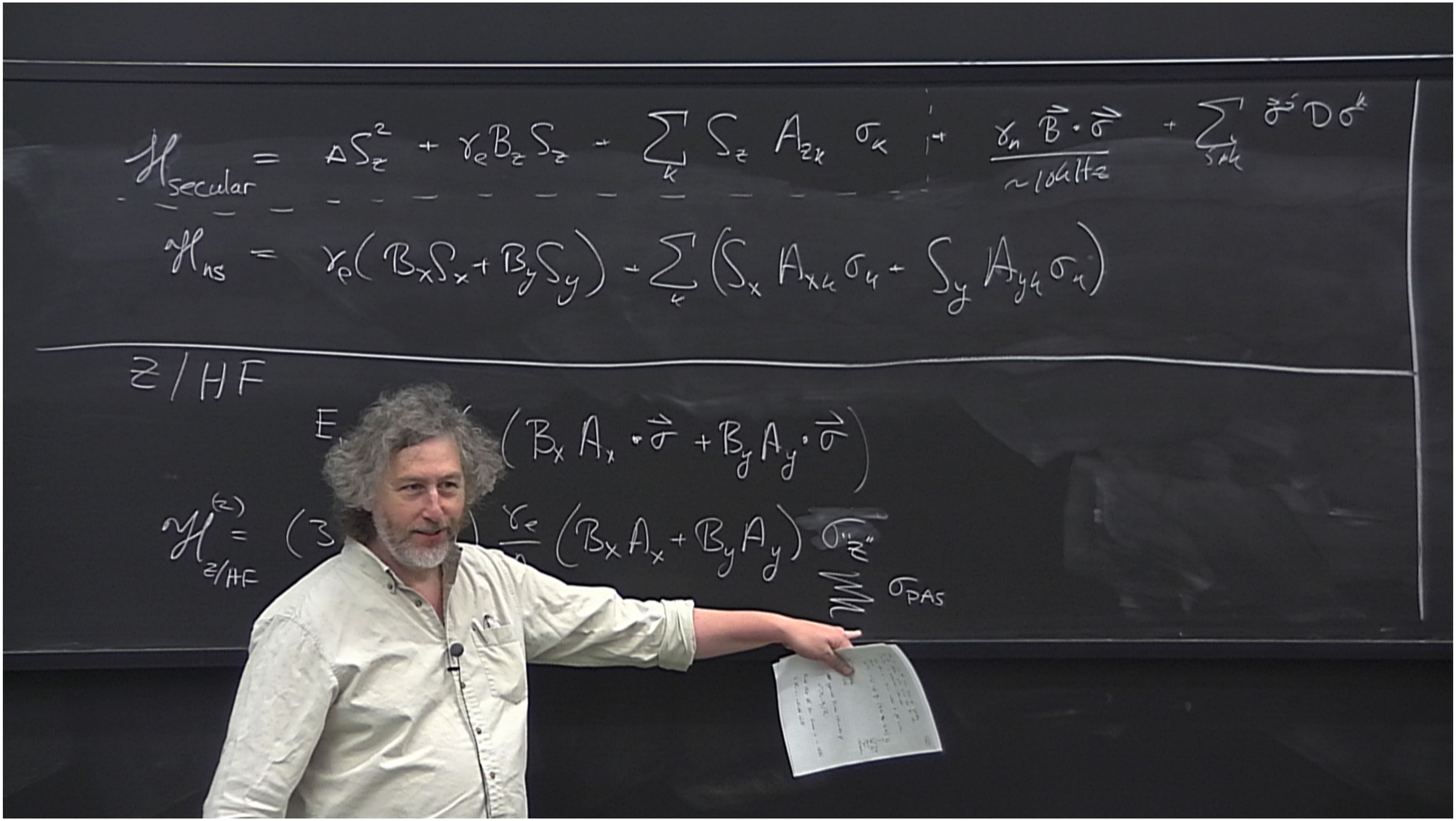
$$\mathcal{H}_{secular} = \Delta S_z^2 + \gamma_e B_z S_z + \sum_k S_z A_{zk} \sigma_k + \underbrace{\gamma_n \vec{B} \cdot \vec{\sigma}}_{\sim 10\,kHz} + \sum_{j \neq k} \sigma^j D \sigma^k$$

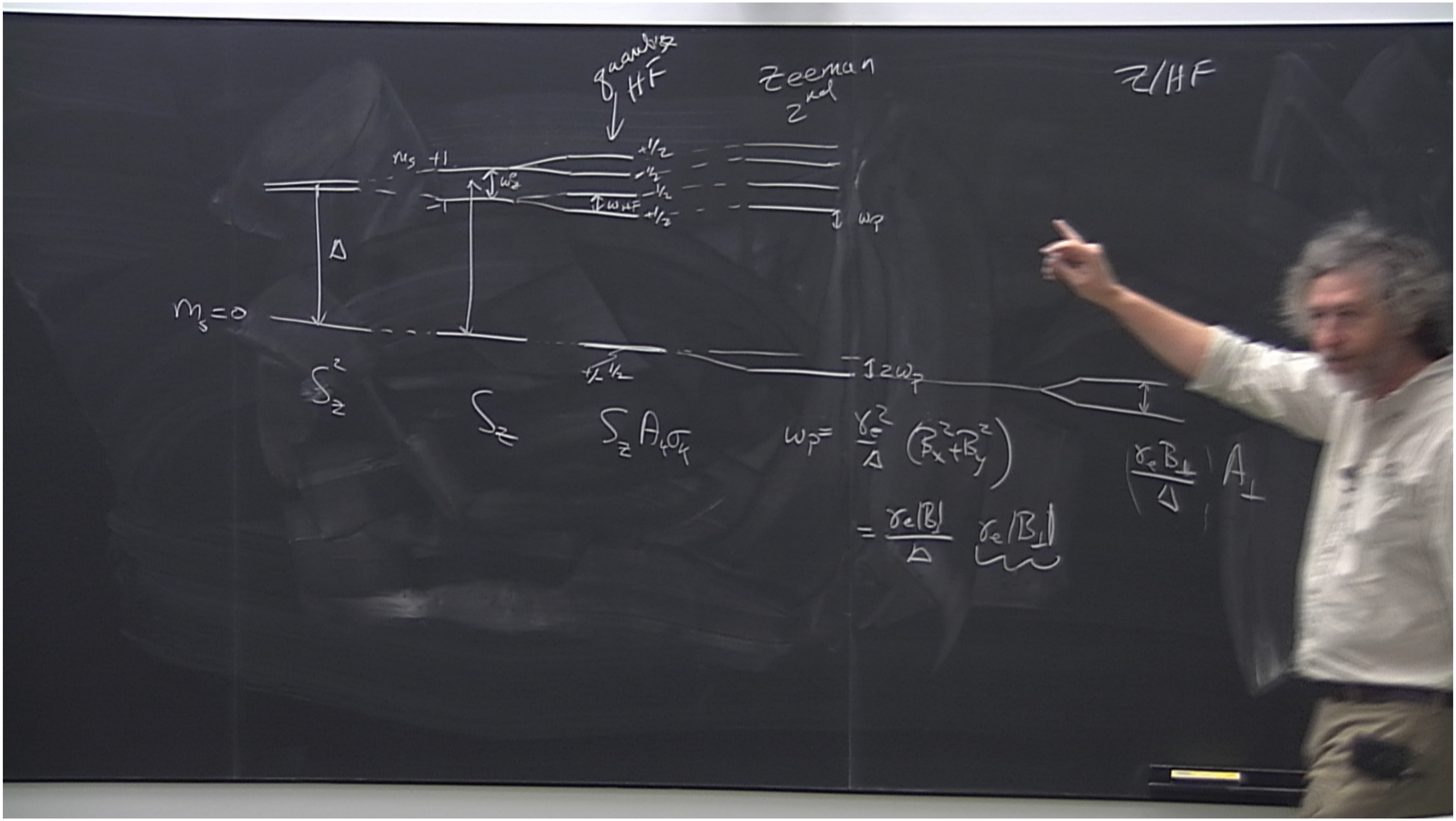
$$\mathcal{H}_{ns} = \gamma_e (B_x S_x + B_y S_y) + \sum_k (S_x A_{xk} \sigma_k + S_y A_{yk} \sigma_k)$$

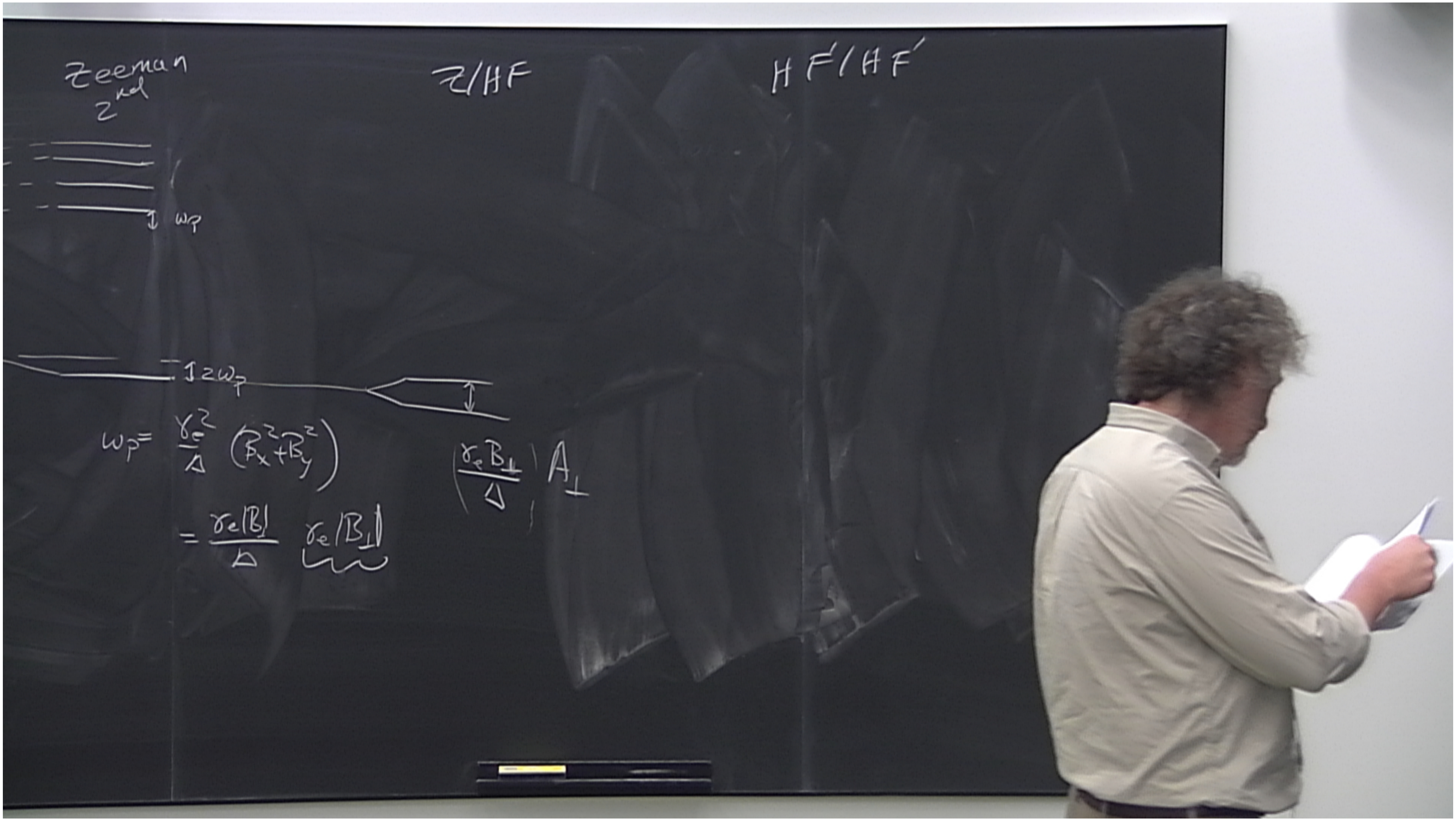
Z/HF

$$E_{m_s = 1} = \frac{\gamma_e}{\Delta} (B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma})$$

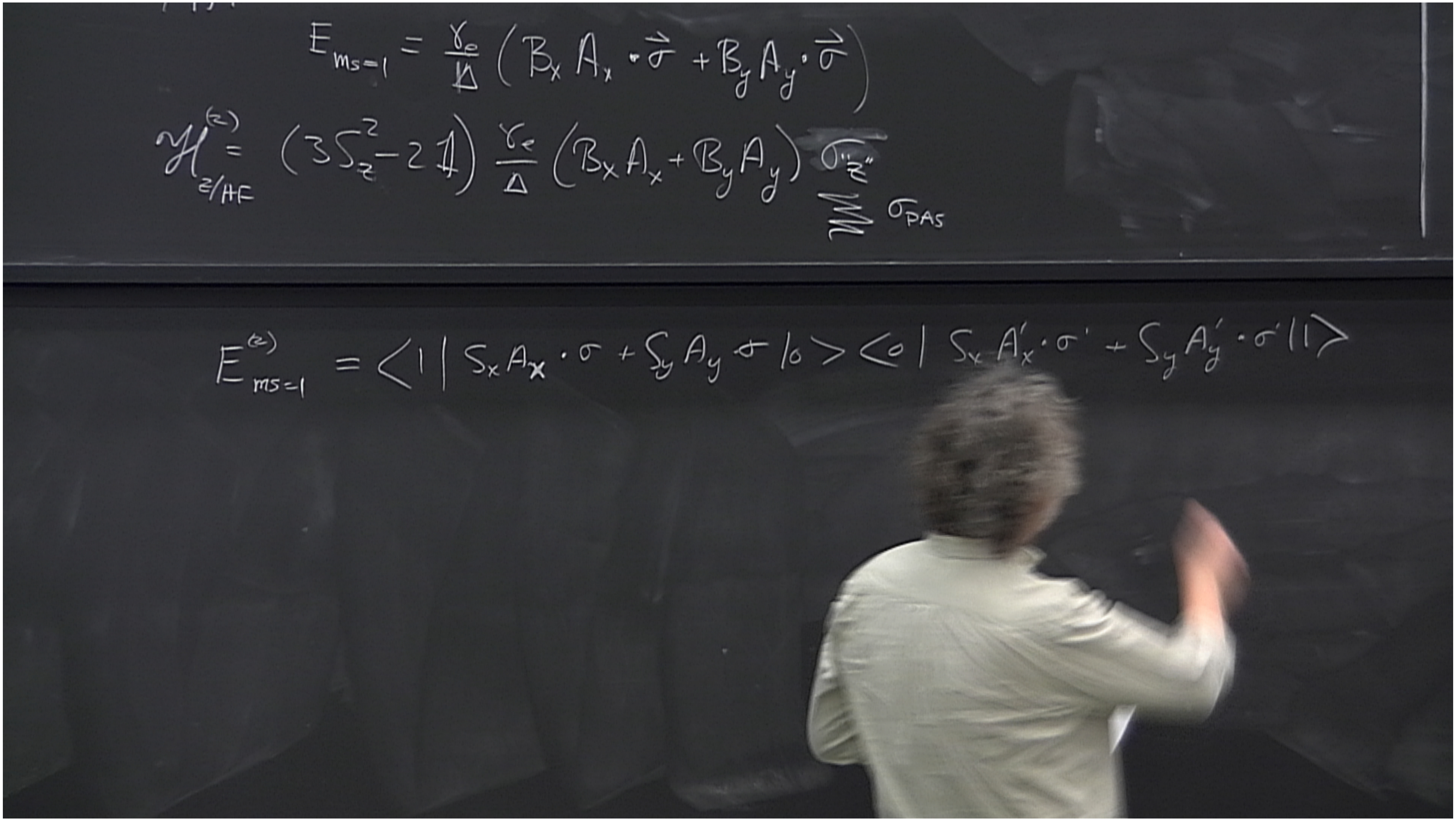
$$\mathcal{H}^{(2)}_{Z/HF} = (3 S_z^2 - 2 \mathbb{1}) \frac{\gamma_e}{\Delta} (B_x A_x + B_y A_y) \sigma_{"z"}$$


H_secular = ΔS_z^2 + γ_e B_z S_z + Σ_k S_z A_zk σ_k + γ_n B⃗·σ⃗ + Σ_{j≠k} σ^j D σ^k
~10kHz
H_ns = γ_e(B_x S_x + B_y S_y) + Σ_k (S_x A_xk σ_k + S_y A_yk σ_k)
Z/HF
σ_PAS


quantized HF
Zeeman
2nd
Z/HF
m_s +1
-1
$m_s = 0$
Δ
ω_Z^e
ω_{HF}
ω_p
$2\omega_p$
S_z^2
S_z
$S_z A_{\perp} \sigma_{\perp}$
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2 + B_y^2)$
$= \frac{\gamma_e |B|}{\Delta} \gamma_e |B_\perp|$
$\left(\frac{\gamma_e B_\perp}{\Delta}\right) A_\perp$



Zeeman
2nd
Z/HF
HF/HF'
ω_p
$2\omega_p$
$\omega_p = \frac{\gamma_e^2}{\Delta}\left(B_x^2 + B_y^2\right)$
$= \frac{\gamma_e |B|}{\Delta} \; \gamma_e |B_\perp|$
$\frac{\gamma_e B_\perp}{\Delta} \; A_\perp$


$E_{m_s=1} = \frac{\gamma_e}{\Delta}\left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma}\right)$
$\mathcal{H}^{(2)}_{e/HF} = \left(3S_z^2 - 2\mathbb{1}\right)\frac{\gamma_e}{\Delta}\left(B_x A_x + B_y A_y\right)\sigma_{\text{"}z\text{"}}$
σ_{PAS}
$E^{(2)}_{m_s=1} = \langle 1 | S_x A_x \cdot \sigma + S_y A_y \sigma | 0 \rangle \langle 0 | S_x A'_x \cdot \sigma' + S_y A'_y \cdot \sigma' | 1 \rangle$

$$E_{m_s=1} = \frac{\gamma_e}{\Delta}\left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma}\right)$$

$$\mathcal{H}^{(2)}_{Z/HF} = \left(3 S_z^2 - 2\mathbb{1}\right)\frac{\gamma_e}{\Delta}\left(B_x A_x + B_y A_y\right)\sigma_{\text{"}z\text{"}} \approx \sigma_{PAS}$$

$$E^{(2)}_{m_s=1} = \langle 1 | S_x A_x \cdot \sigma + S_y A_y \sigma | 0 \rangle \langle 0 | S_x A'_x \cdot \sigma' + S_y A'_y \cdot \sigma' | 1 \rangle + hc$$

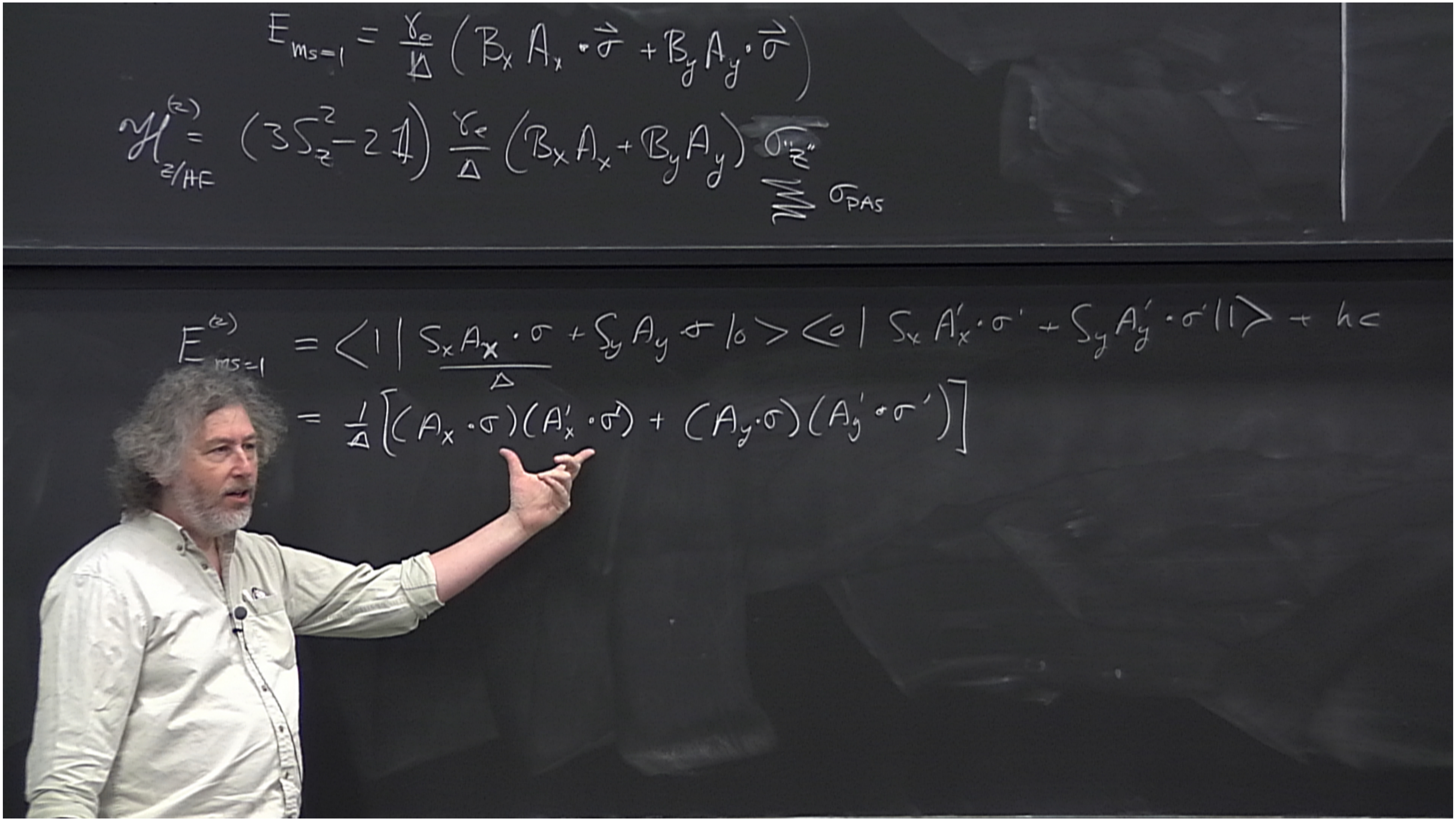
$$E_{m_s=1} = \frac{\gamma_e}{\Delta}\left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma}\right)$$

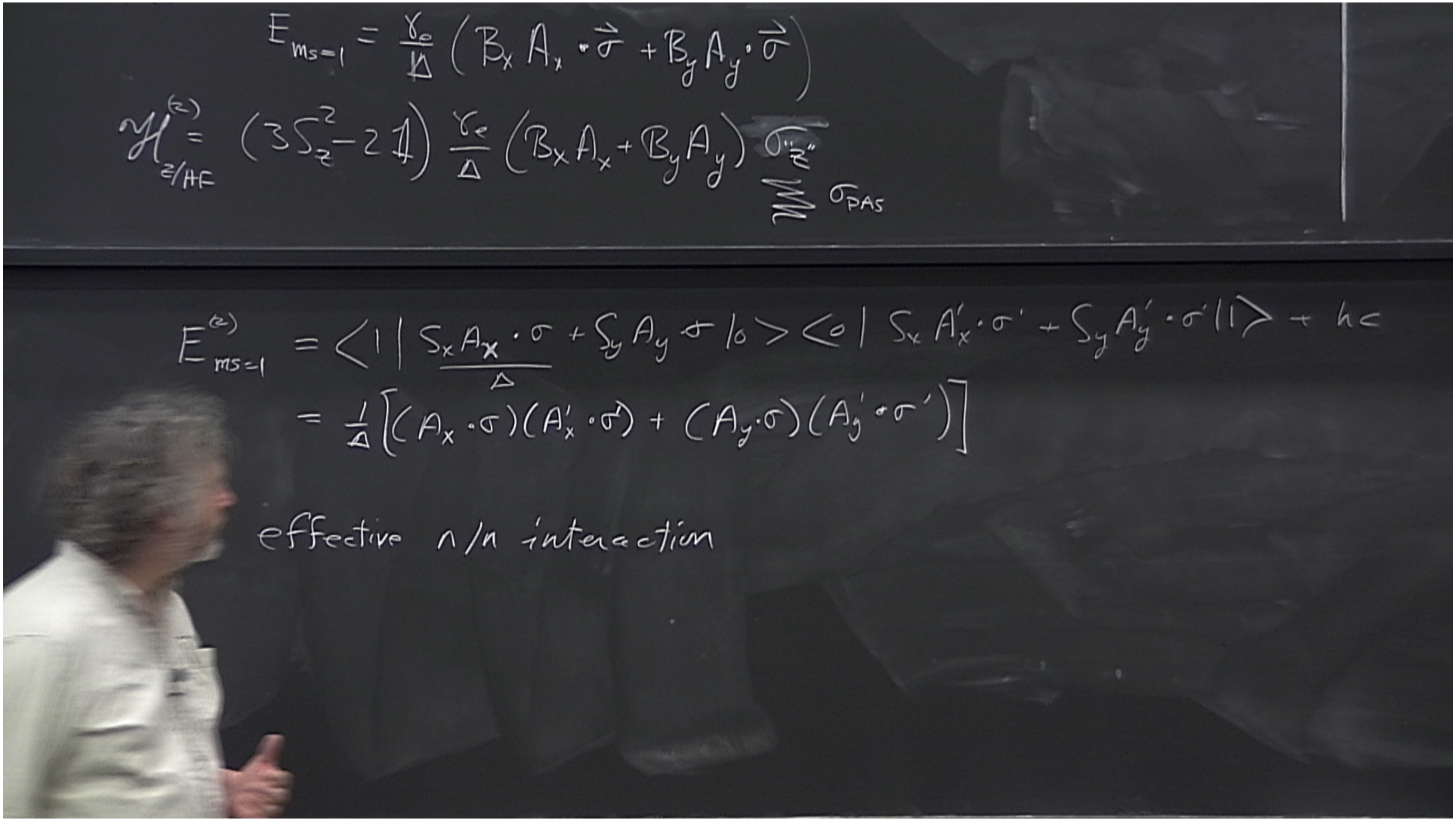
$$\mathcal{H}^{(2)}_{z/HF} = \left(3S_z^2 - 2\mathbb{1}\right) \frac{\gamma_e}{\Delta}\left(B_x A_x + B_y A_y\right) \sigma_{\text{"}z\text{"}}$$

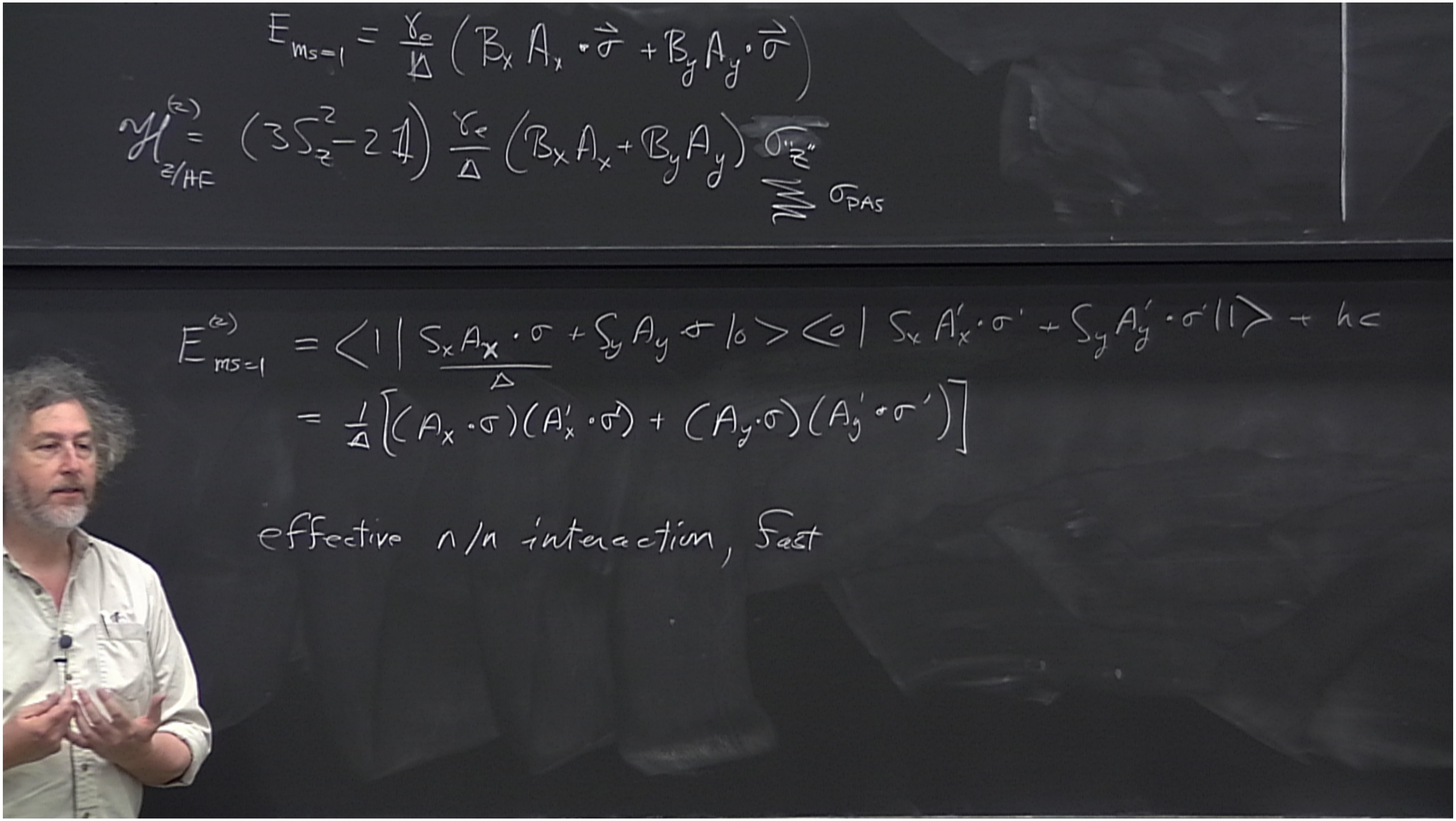
$$\approx \sigma_{PAS}$$

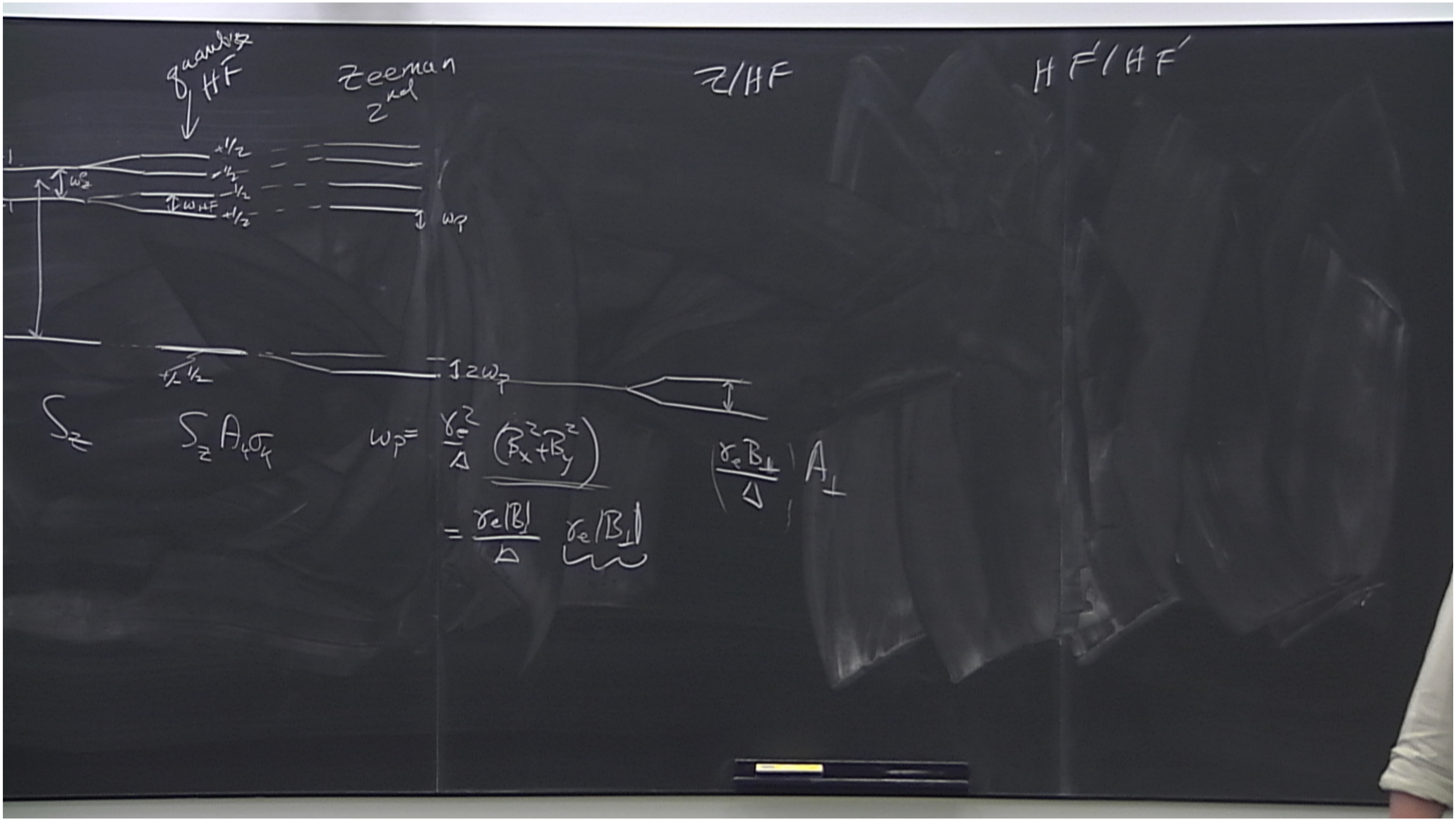
$$E^{(2)}_{m_s=1} = \langle 1 | \frac{S_x A_x \cdot \sigma + S_y A_y \cdot \sigma}{\Delta} | 0 \rangle \langle 0 | S_x A'_x \cdot \sigma' + S_y A'_y \cdot \sigma' | 1 \rangle + hc$$

$$= \frac{1}{\Delta}\left[(A_x \cdot \sigma)(A'_x \cdot \sigma) + (A_y \cdot \sigma)(A'_y \cdot \sigma')\right]$$


$E_{m_s=1} = \frac{\gamma_e}{\Delta}\left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma}\right)$
$\mathcal{H}^{(2)}_{Z/HF} = \left(3S_z^2 - 2\mathbb{1}\right)\frac{\gamma_e}{\Delta}\left(B_x A_x + B_y A_y\right)\sigma_{"z"}$
$\equiv \sigma_{PAS}$
$E^{(2)}_{m_s=1} = \langle 1 | \frac{S_x A_x \cdot \sigma}{\Delta} + S_y A_y \sigma | 0 \rangle \langle 0 | S_x A'_x \cdot \sigma' + S_y A'_y \cdot \sigma' | 1 \rangle + hc$
$= \frac{1}{\Delta}\left[(A_x \cdot \sigma)(A'_x \cdot \sigma') + (A_y \cdot \sigma)(A'_y \cdot \sigma')\right]$


$E_{m_s=1} = \frac{\gamma_e}{\Delta}\left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma}\right)$
$\mathcal{H}^{(2)}_{Z/HF} = \left(3S_z^2 - 2\mathbb{1}\right)\frac{\gamma_e}{\Delta}\left(B_x A_x + B_y A_y\right)\sigma_{"z"}$
σ_{PAS}
$E^{(2)}_{m_s=1} = \langle 1 | \frac{S_x A_x \cdot \sigma}{\Delta} + S_y A_y \sigma | 0 \rangle \langle 0 | S_x A'_x \cdot \sigma' + S_y A'_y \cdot \sigma' | 1 \rangle + hc$
$= \frac{1}{\Delta}\left[(A_x \cdot \sigma)(A'_x \cdot \sigma') + (A_y \cdot \sigma)(A'_y \cdot \sigma')\right]$
effective n/n interaction


$E_{m_s=1} = \frac{\gamma_e}{\Delta}\left(B_x A_x \cdot \vec{\sigma} + B_y A_y \cdot \vec{\sigma}\right)$
$\mathcal{H}^{(2)}_{Z/HF} = (3S_z^2 - 2\mathbb{1})\,\frac{\gamma_e}{\Delta}(B_x A_x + B_y A_y)\,\sigma_{\text{"}z\text{"}}$
σ_{PAS}
$E^{(2)}_{m_s=1} = \langle 1 |\, \frac{S_x A_x \cdot \sigma}{\Delta} + S_y A_y \sigma \,| 0 \rangle \langle 0 |\, S_x A'_x \cdot \sigma' + S_y A'_y \cdot \sigma' \,| 1 \rangle + hc$
$= \frac{1}{\Delta}\left[(A_x \cdot \sigma)(A'_x \cdot \sigma') + (A_y \cdot \sigma)(A'_y \cdot \sigma')\right]$
effective n/n interaction, fast


HF
Zeeman
2nd
Z/HF
HF/HF'
+1/2
-1/2
ωZ
ωHF
ωp
2ωp
Sz
Sz Ak σk
ωp = γe²/Δ (Bx² + By²)
= γe|B|/Δ γe|B⊥|
γe B⊥/Δ A⊥

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Mon 2:41 PM dcory

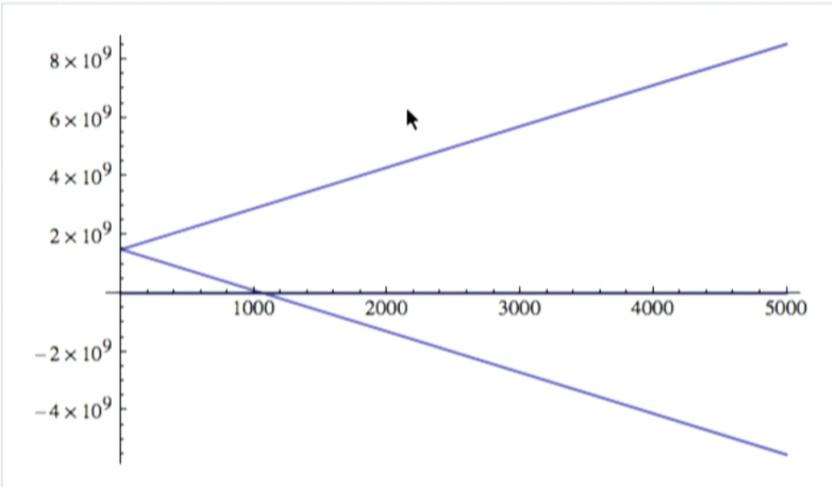
NV anticrossing.nb

In[25]:=
```
Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, 5000}], {wHF, 0, 2.5 × 10^5},
 {θ, 0, π / 2}]
```

wHF

θ

Out[25]=



In[26]:=
```
Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 1060, 1080}, {PlotRange → {-.1 10^8, .1 × 10^8}}],
 {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
```

wHF

θ

150%

100%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Mon 2:43 PM dcory

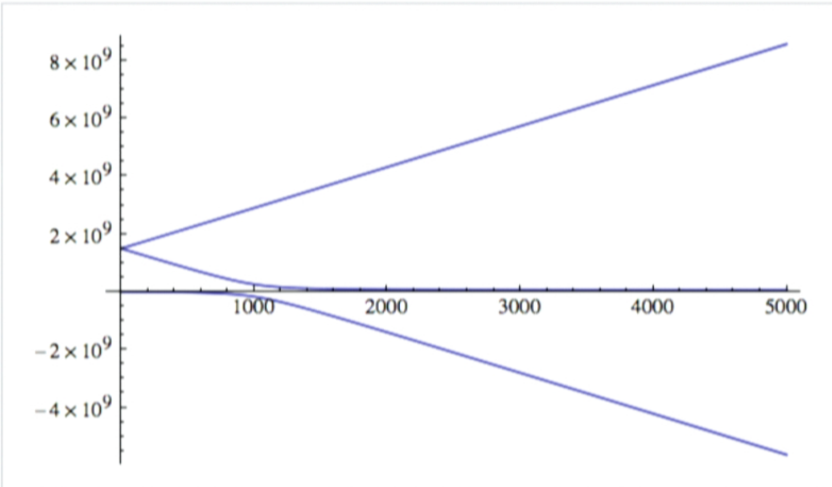
NV anticrossing.nb

In[25]:=
```
Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, 5000}], {wHF, 0, 2.5 × 10^5},
 {θ, 0, π / 2}]
```

wHF

θ

Out[25]=



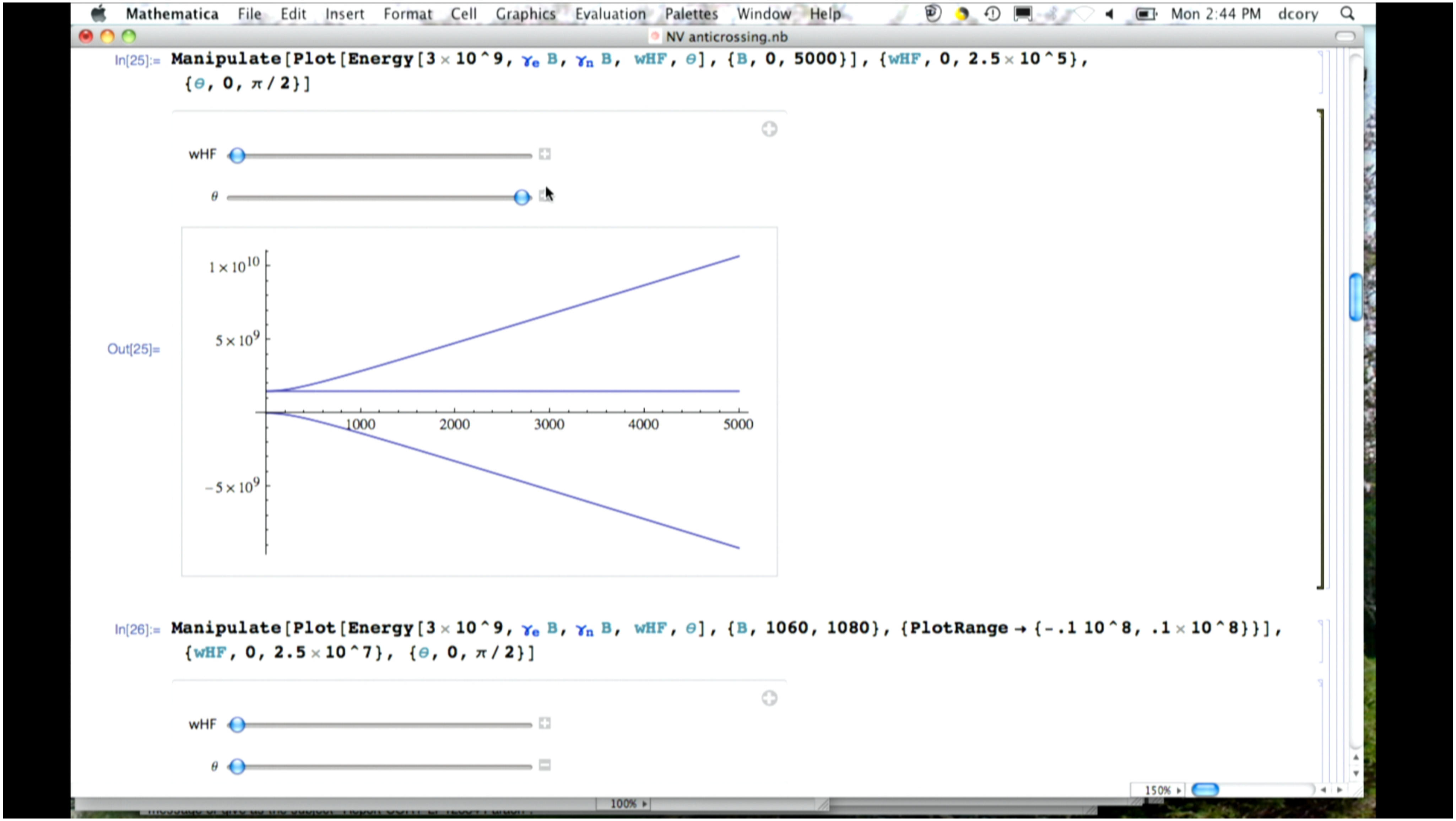
In[26]:=
```
Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 1060, 1080}, {PlotRange → {-.1 10^8, .1 × 10^8}}],
 {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
```

wHF

θ

100%

150%


Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Mon 2:44 PM dcory
NV anticrossing.nb
In[25]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, 5000}], {wHF, 0, 2.5 × 10^5},
{θ, 0, π / 2}]
wHF
θ
Out[25]=
1 × 10^10
5 × 10^9
−5 × 10^9
1000
2000
3000
4000
5000
In[26]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 1060, 1080}, {PlotRange → {-.1 10^8, .1 × 10^8}}],
{wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
wHF
θ
150%
100%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Mon 2:45 PM dcory

NV anticrossing.nb

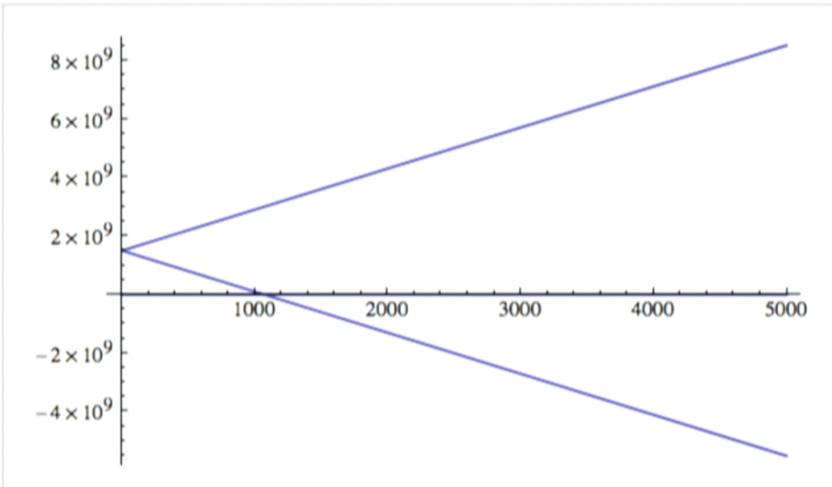
```
In[24]:= Energy[wZF_,we_,wn_,wHF_, θ_]:= Sort[Eigenvalues[H[wZF,we,wn,wHF, θ]]]

In[25]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, 5000}], {wHF, 0, 2.5 × 10^5},
  {θ, 0, π / 2}]
```

wHF

θ

Out[25]=




```
In[26]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 1060, 1080}, {PlotRange → {-.1 10^8, .1 × 10^8}}],
  {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
```

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help Mon 2:45 PM dcory

NV anticrossing.nb

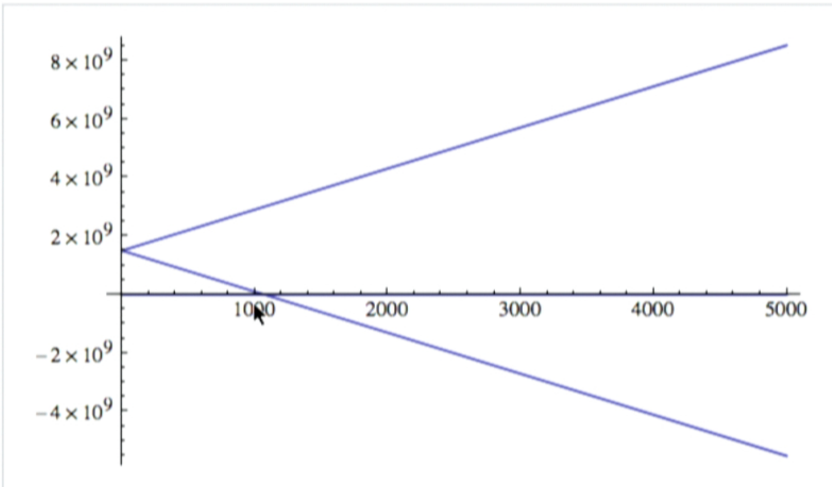
```
In[24]:= Energy[wZF_,we_,wn_,wHF_, θ_]:= Sort[Eigenvalues[H[wZF,we,wn,wHF, θ]]]

In[25]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, 5000}], {wHF, 0, 2.5 × 10^5},
  {θ, 0, π / 2}]
```

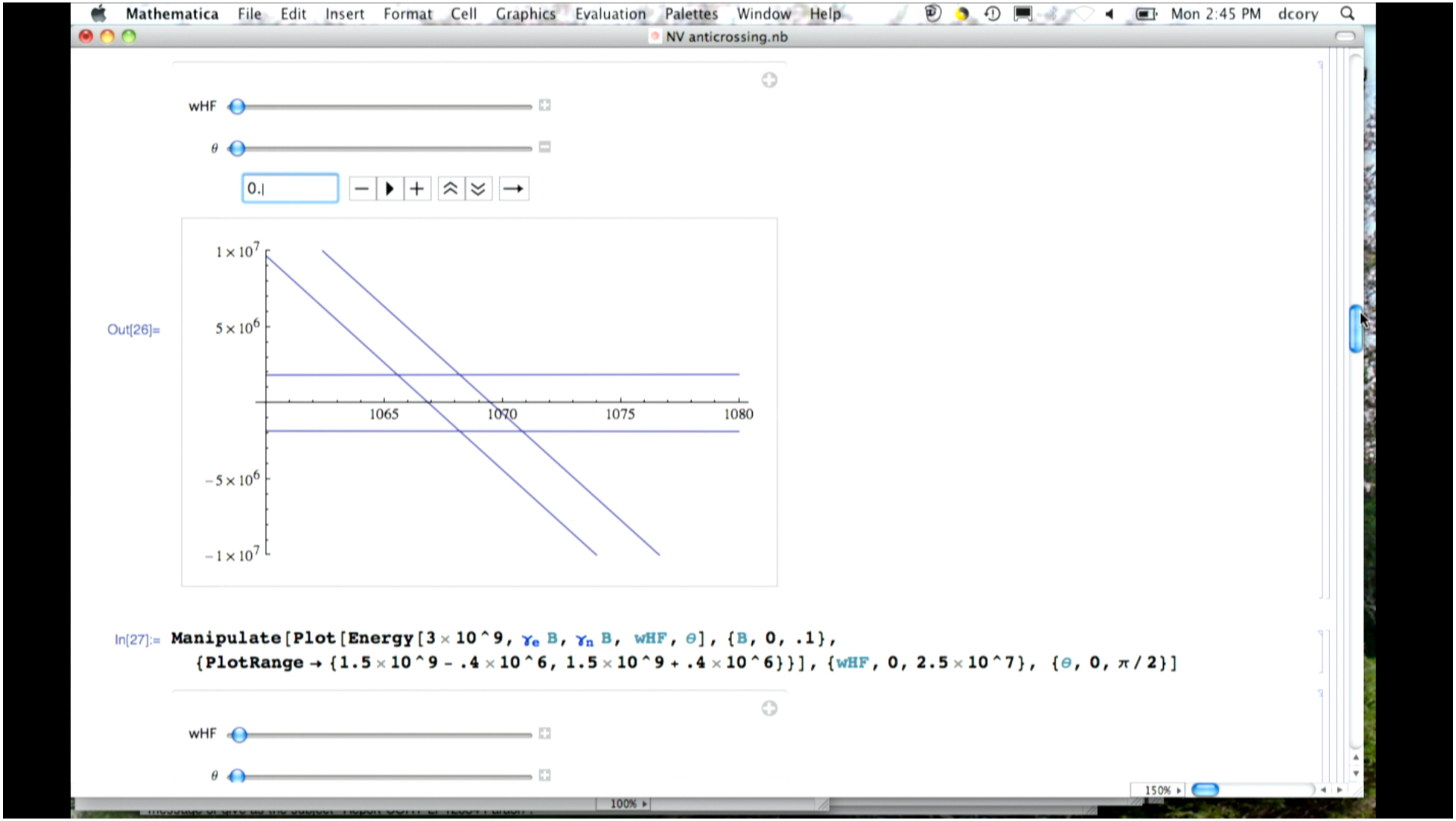
wHF

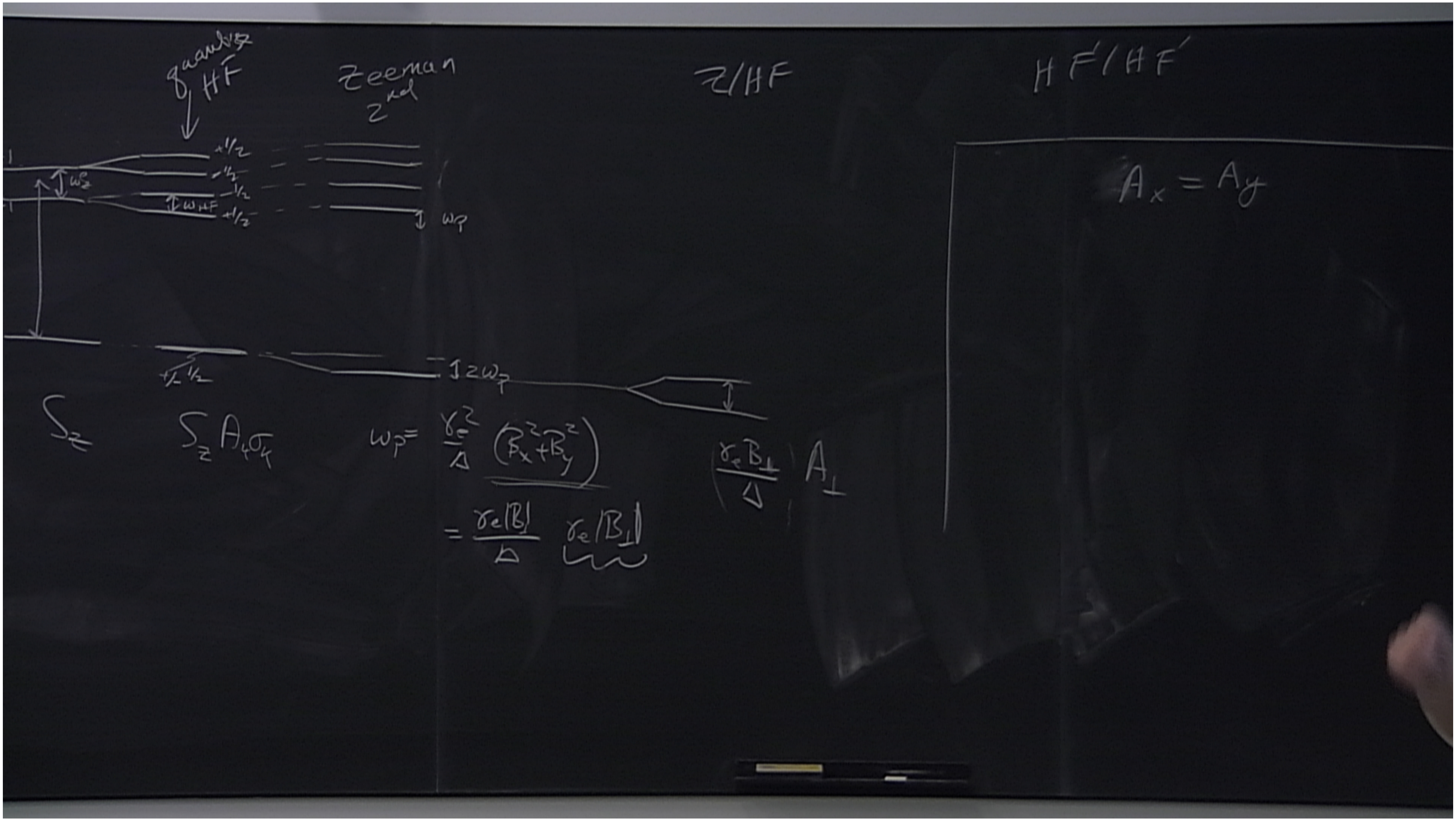
θ

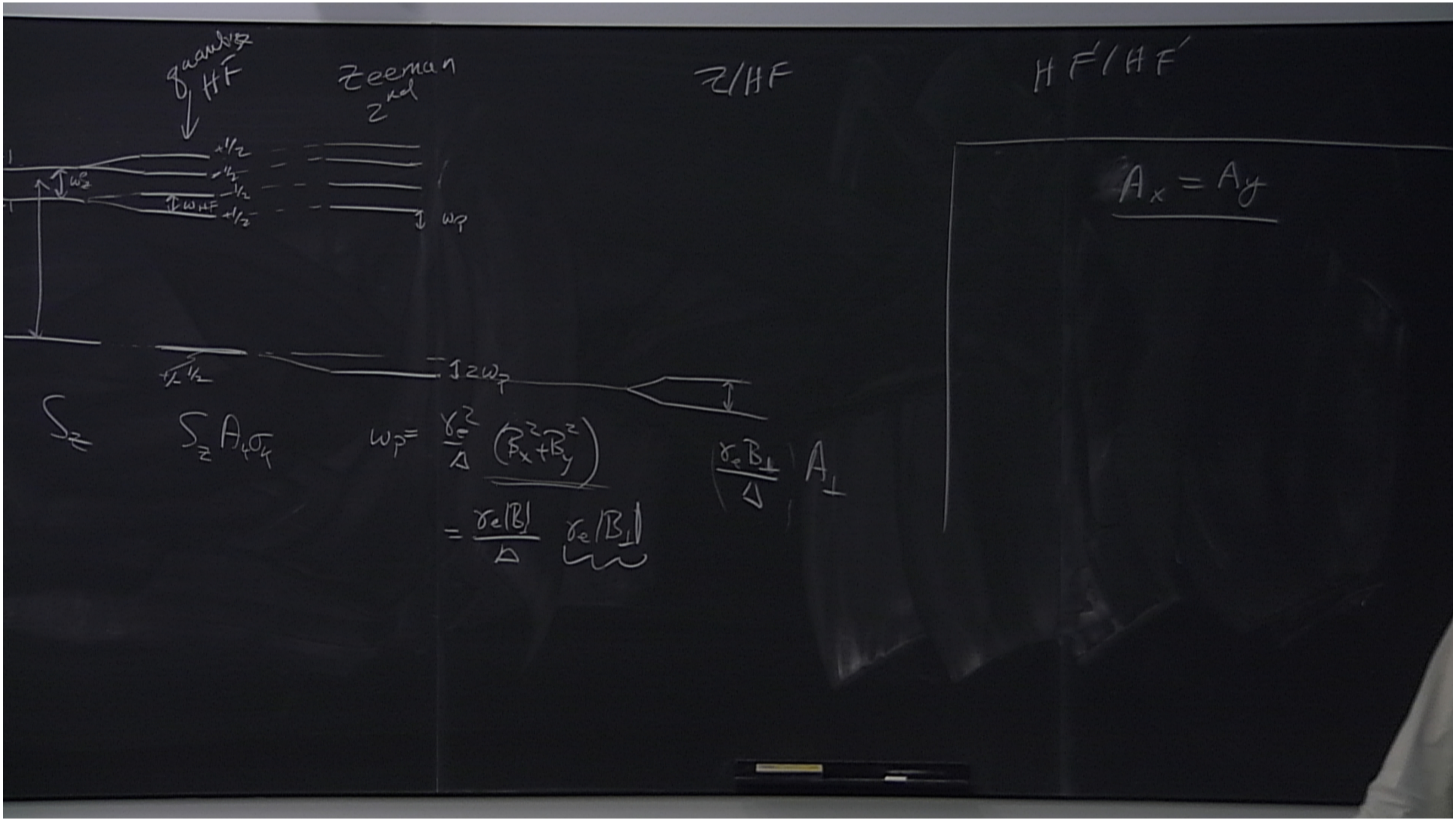
Out[25]=

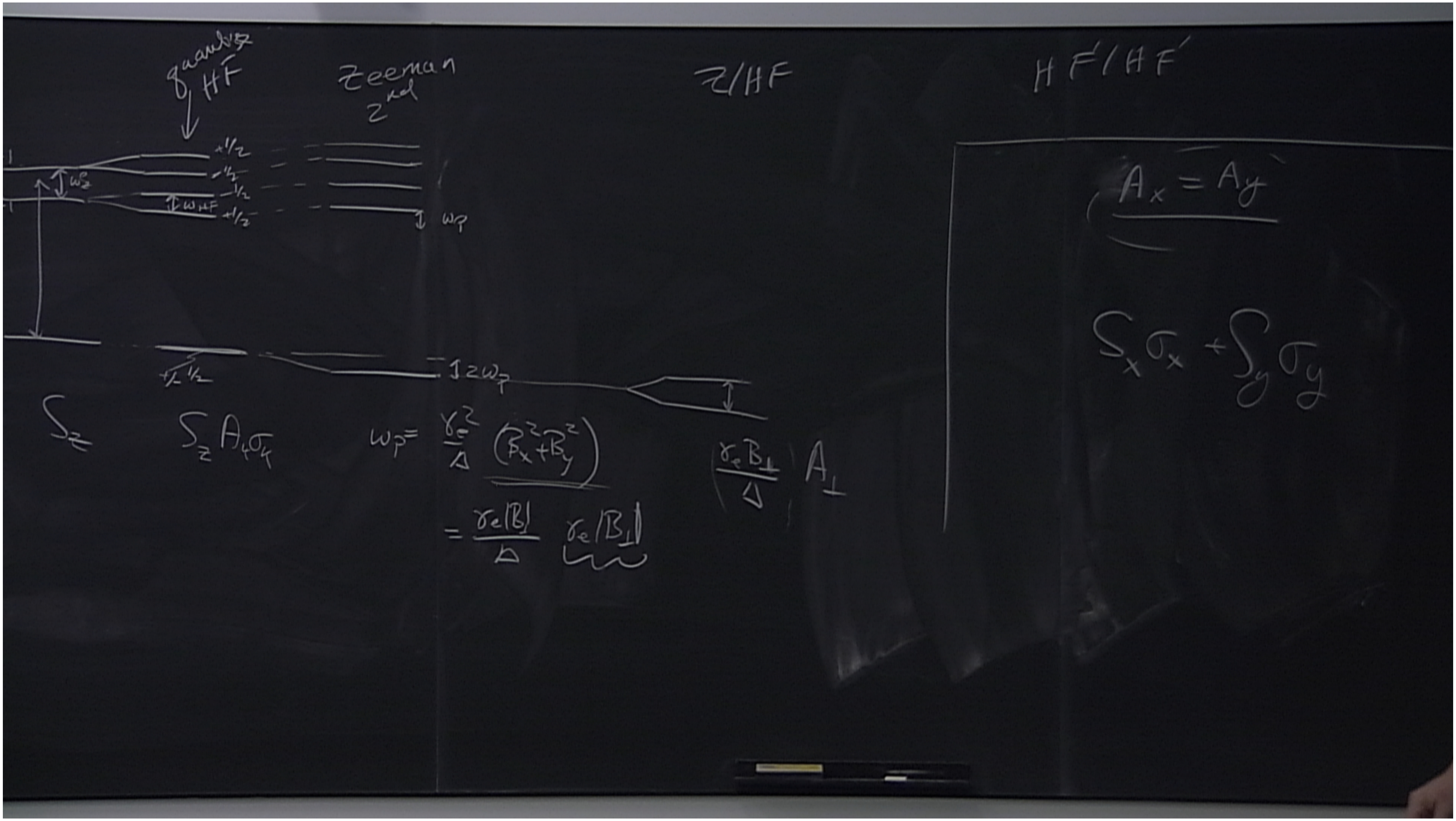


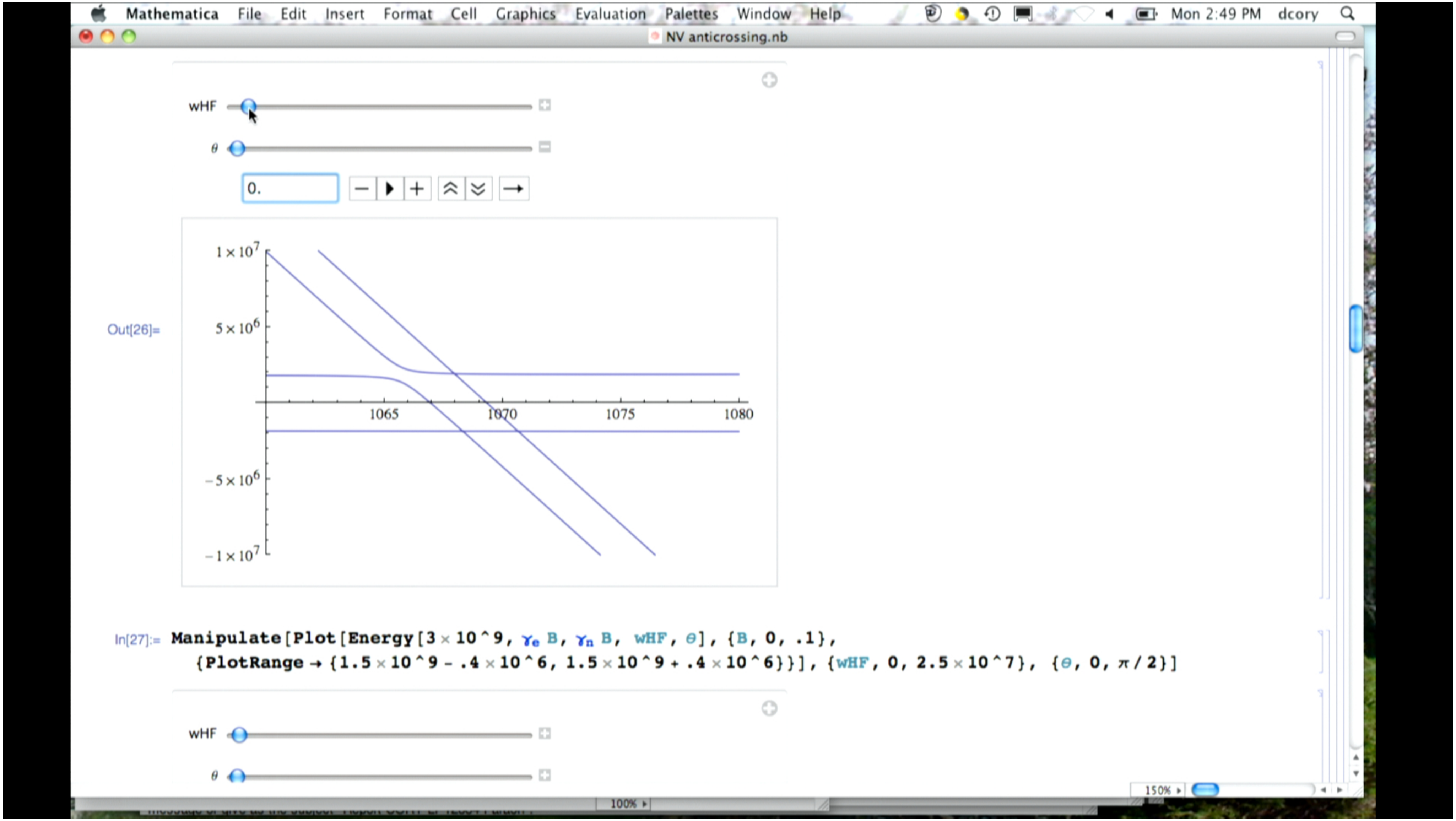

```
In[26]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 1060, 1080}, {PlotRange → {-.1 10^8, .1 × 10^8}}],
  {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
```

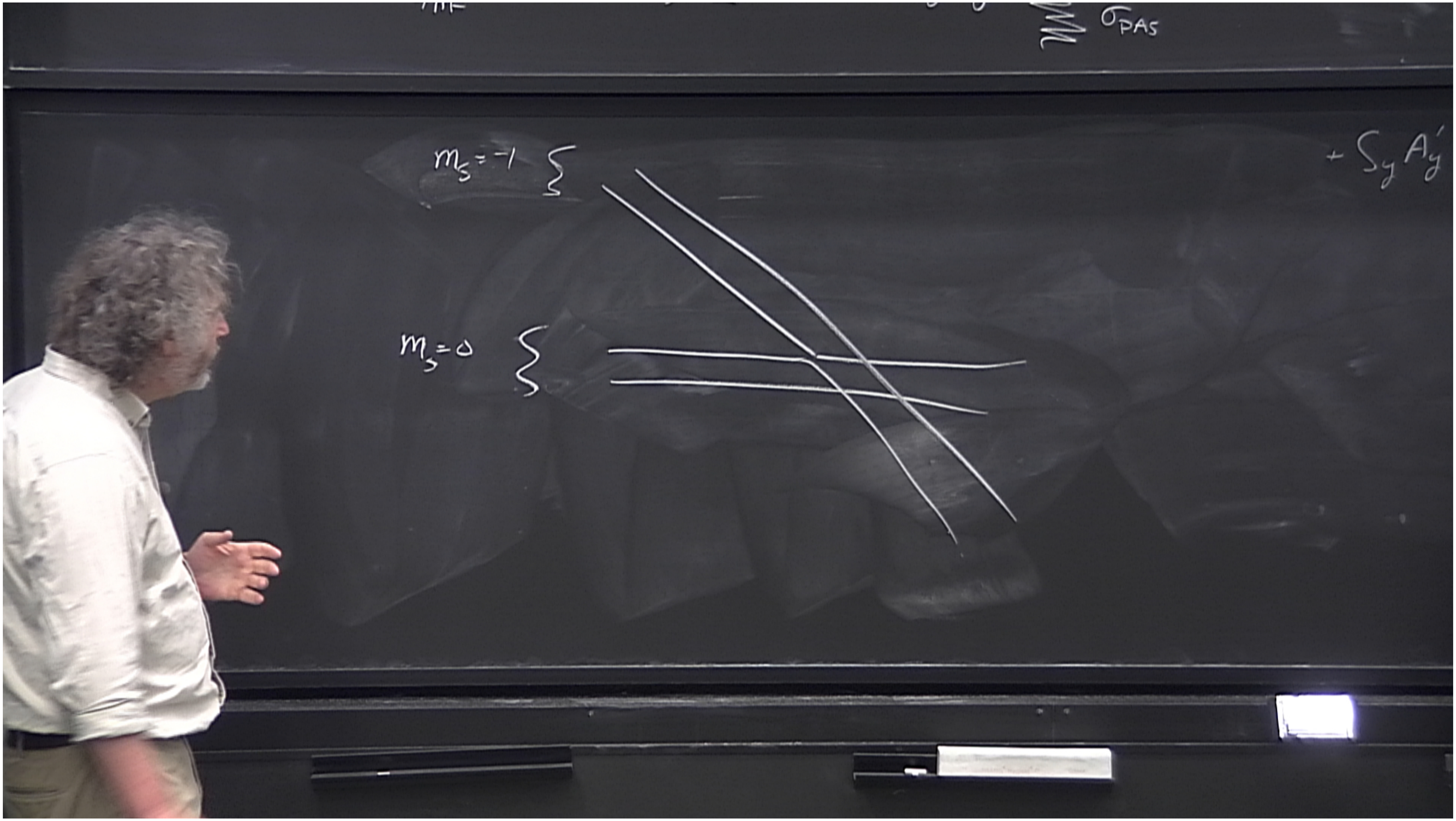

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Mon 2:45 PM dcory
NV anticrossing.nb
wHF
θ
0.
Out[26]=
1 × 10^7
5 × 10^6
−5 × 10^6
−1 × 10^7
1065
1070
1075
1080
In[27]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, .1},
{PlotRange → {1.5 × 10^9 - .4 × 10^6, 1.5 × 10^9 + .4 × 10^6}}], {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
wHF
θ
150%
100%

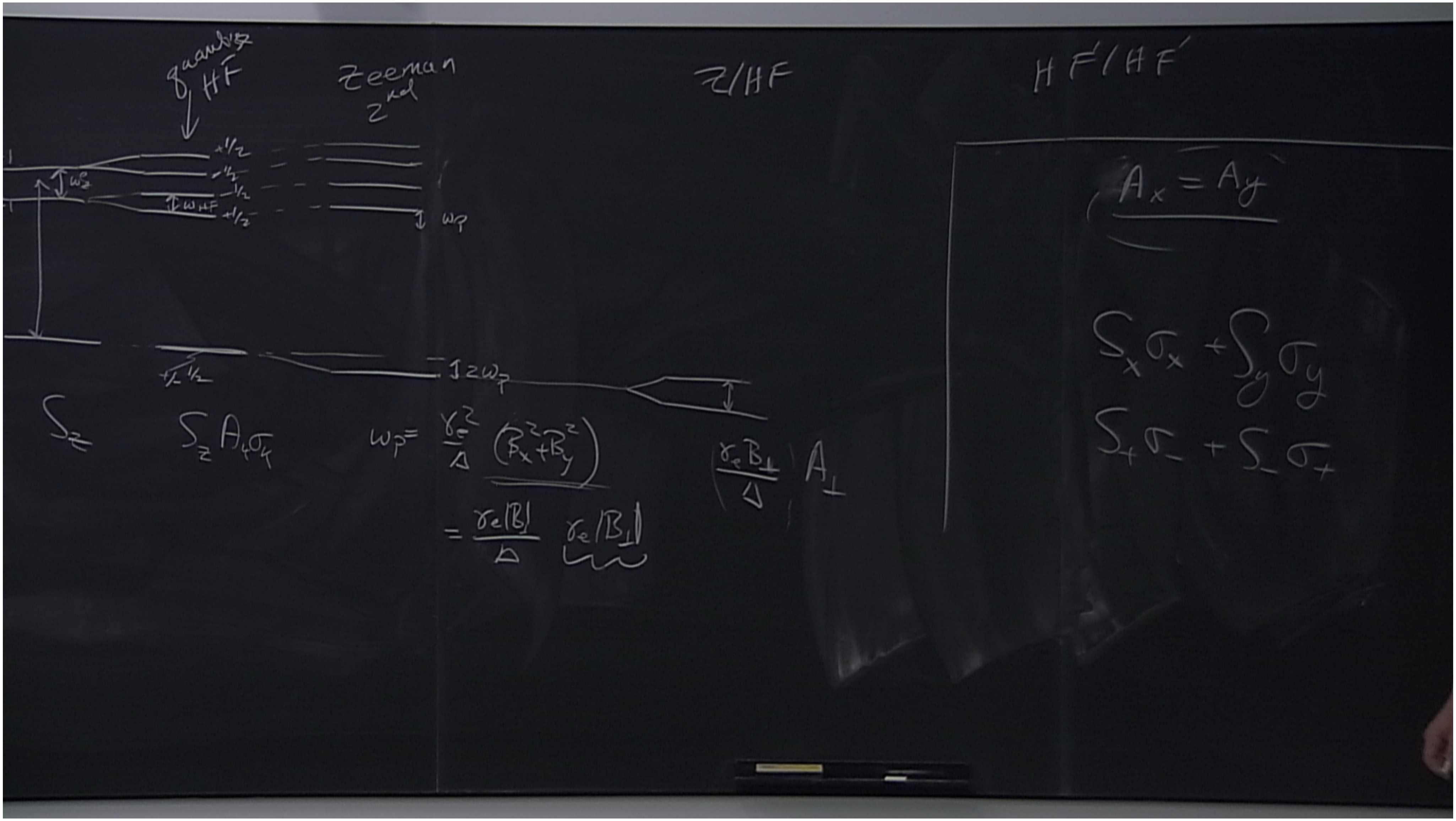

quantize HF
Zeeman 2nd
Z/HF
HF/HF'
$A_x = A_y$
ω_z
ω_{HF}
ω_p
$2\omega_p$
S_z
$S_z A_k \sigma_k$
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2 + B_y^2)$
$= \frac{\gamma_e |B|}{\Delta} \gamma_e |B_\perp|$
$\frac{\gamma_e B_\perp}{\Delta} A_\perp$

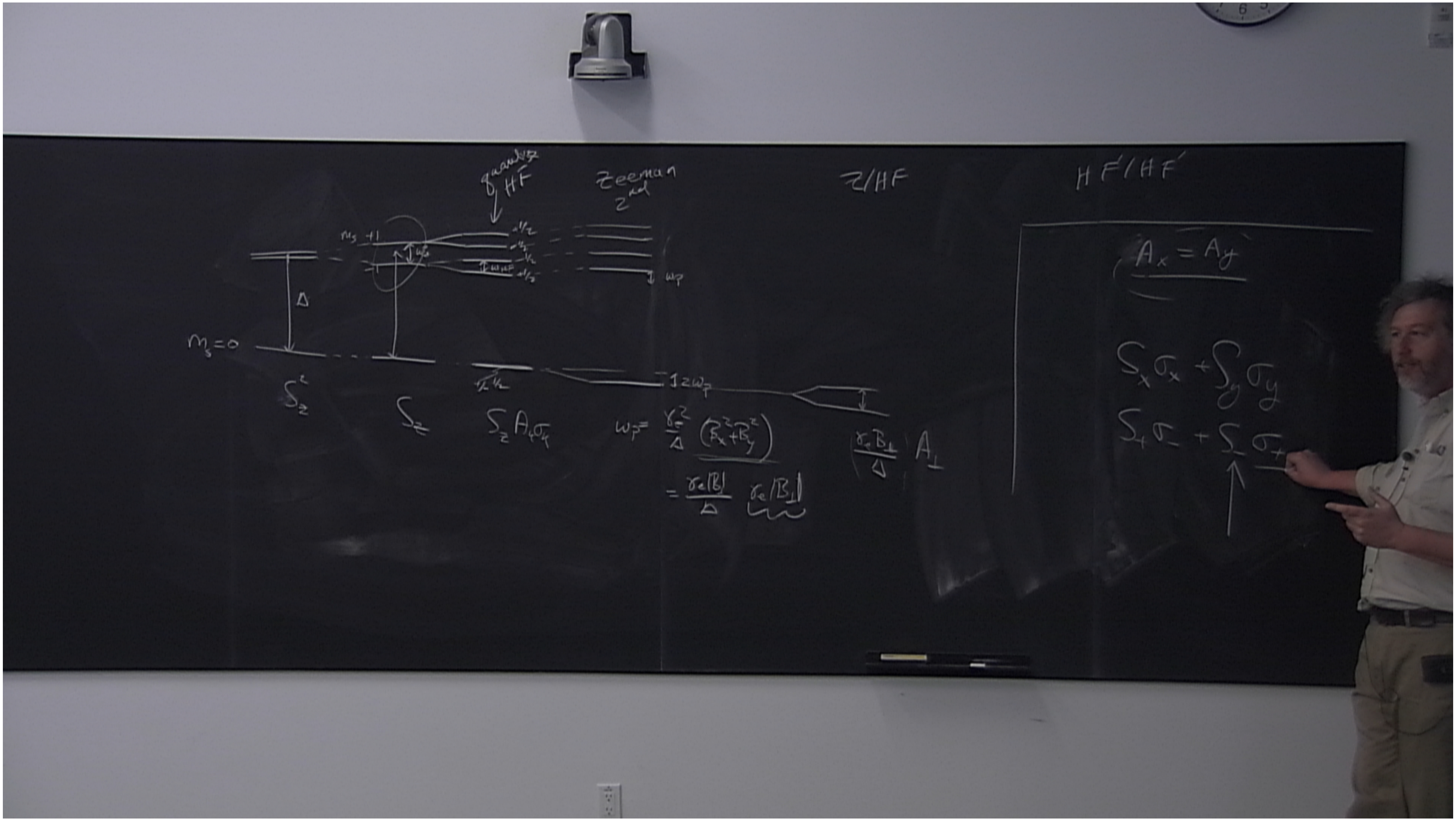

quantize HF
Zeeman
2nd
Z/HF
HF/HF′
+1/2
-1/2
ω_{HF}
ω_p
$2\omega_p$
S_z
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2+B_y^2)$
$= \frac{\gamma_e|B|}{\Delta}$
$\gamma_e|B_\perp|$
$\frac{\gamma_e B_\perp}{\Delta}$
$A_\perp$
$A_x = A_y$

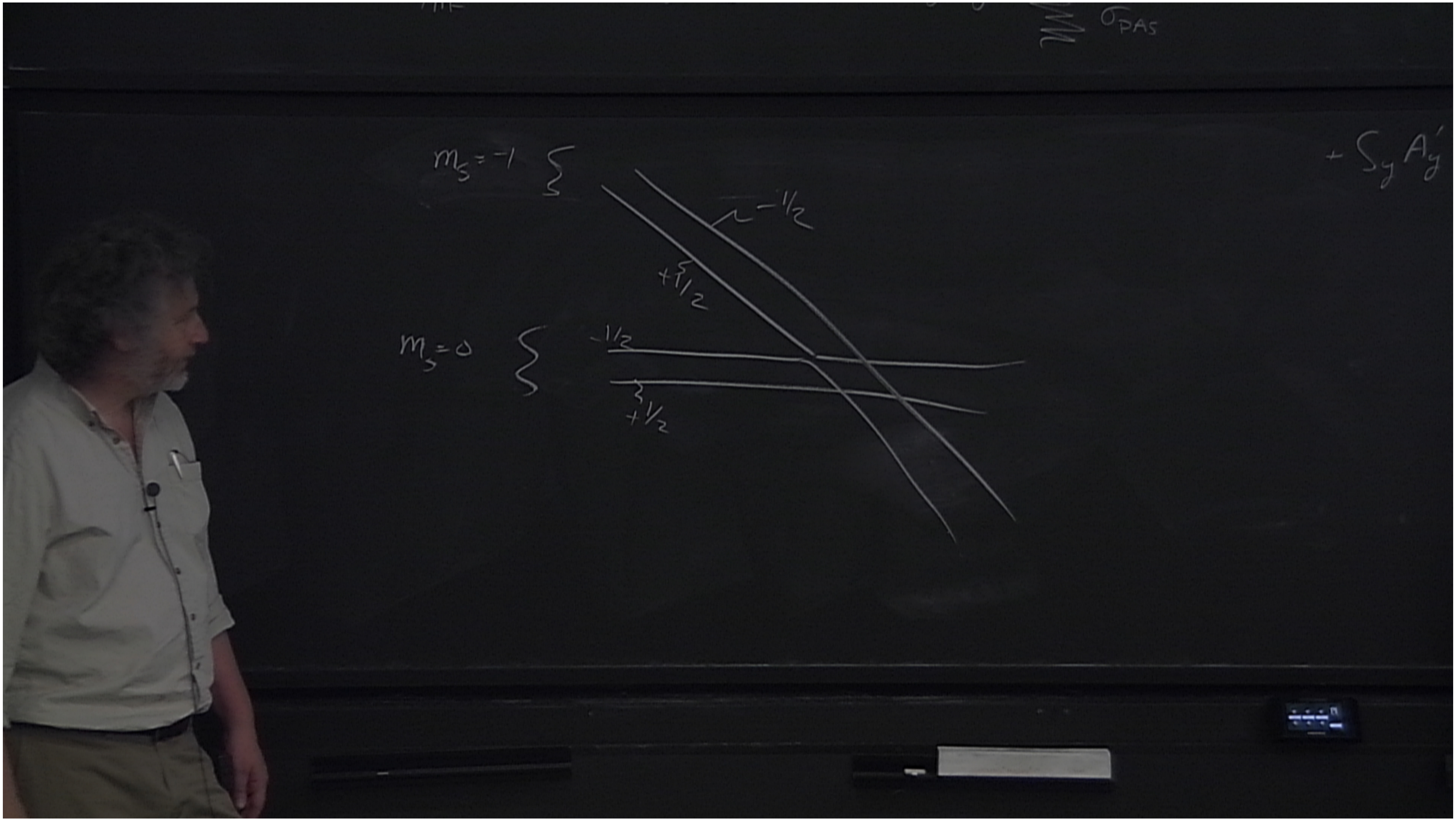

quantize HF
Zeeman
2nd
Z/HF
HF/HF'
+1/2
-1/2
-1/2
+1/2
ω_z
ω_{HF}
ω_p
$2\omega_p$
$A_x = A_y$
S_z
$S_z A_z \sigma_z$
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2 + B_y^2)$
$= \frac{\gamma_e |B|}{\Delta} \quad \gamma_e |B_\perp|$
$\frac{\gamma_e B_\perp}{\Delta} \quad A_\perp$
$S_x \sigma_x + S_y \sigma_y$


Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Mon 2:49 PM dcory
NV anticrossing.nb
wHF
θ
0.
Out[26]=
1 × 10^7
5 × 10^6
−5 × 10^6
−1 × 10^7
1065
1070
1075
1080
In[27]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, .1},
{PlotRange → {1.5 × 10^9 - .4 × 10^6, 1.5 × 10^9 + .4 × 10^6}}], {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
wHF
θ
150%
100%

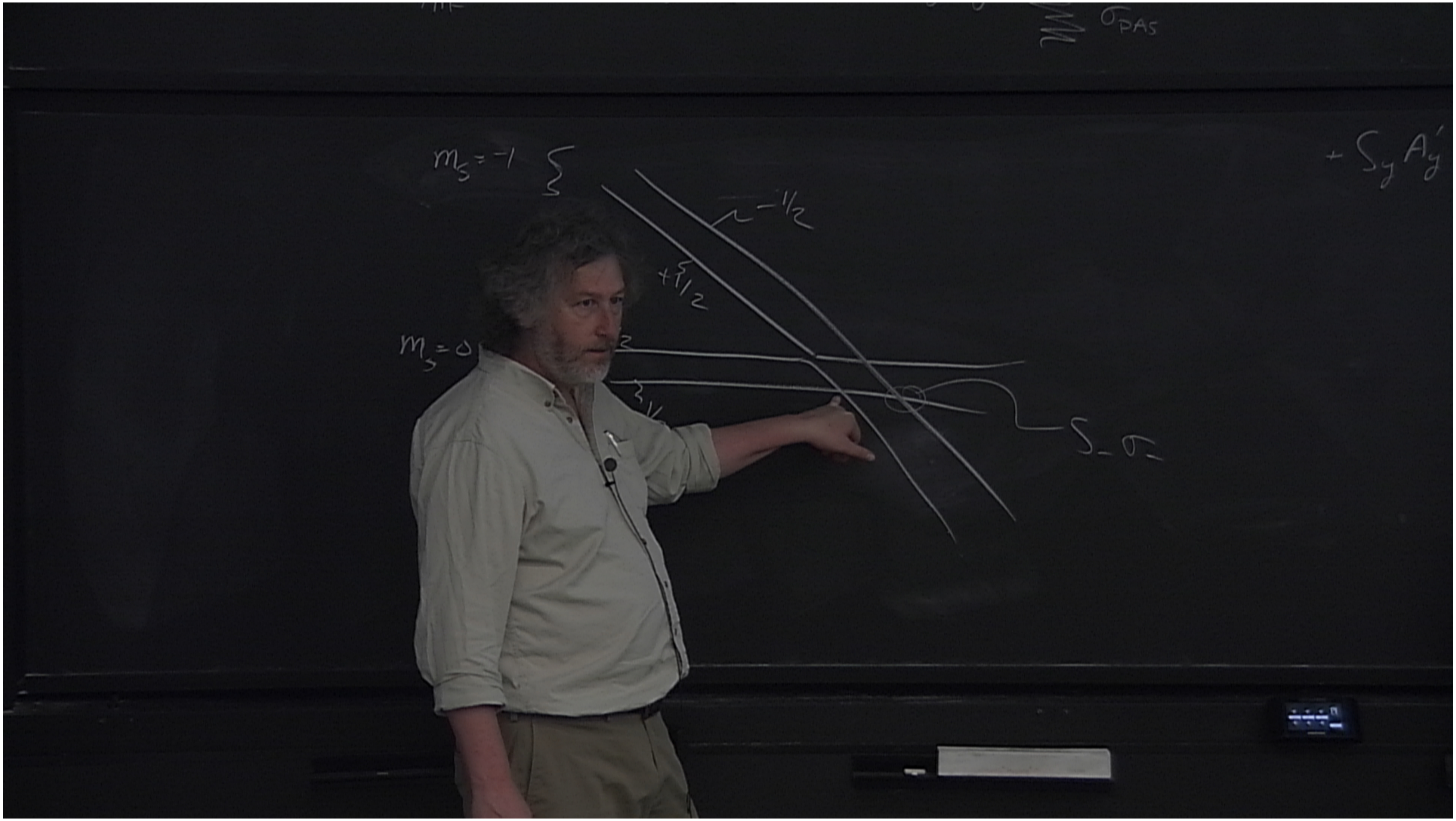

σ_{PAS}
$m_s = -1$
$+ S_y A_y'$
$m_s = 0$


quantize HF
Zeeman 2nd
Z/HF
HF/HF'
ω_z
ω_HF
ω_p
+1/2
-1/2
2ω_p
S_z
S_z A_y σ_y
ω_p = γ_e²/Δ (B_x² + B_y²)
= γ_e|B|/Δ γ_e|B_⊥|
γ_e B_⊥/Δ A_⊥
A_x = A_y
S_x σ_x + S_y σ_y
S_+ σ_- + S_- σ_+

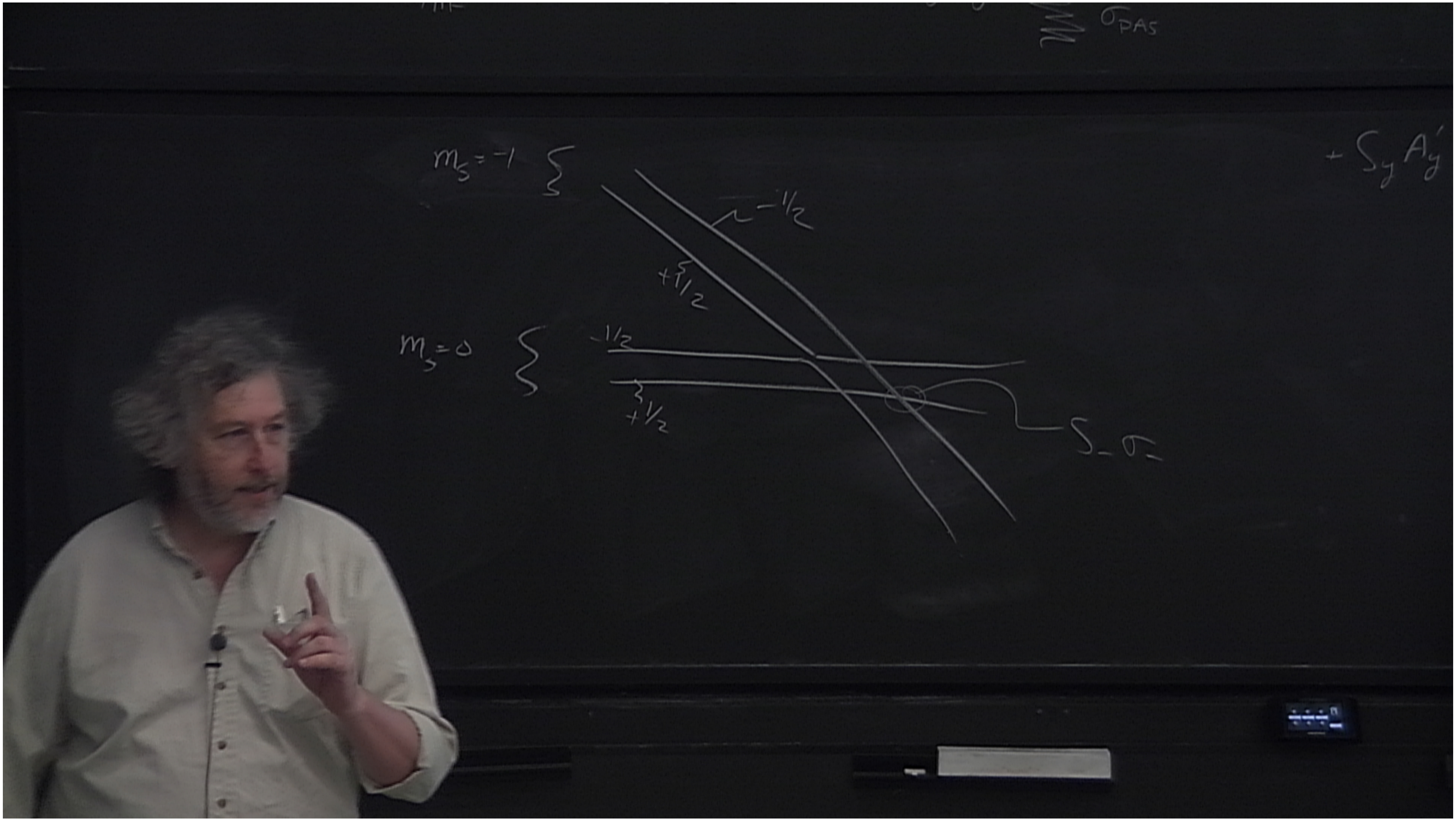

HF
Zeeman
2nd
Z/HF
HF/HF'
$m_s = +1$
$m_s = 0$
Δ
ω_p
$12\omega_p$
S_z^2
S_z
$S_z A_\parallel \sigma_\parallel$
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2 + B_y^2)$
$= \frac{\gamma_e |B|}{\Delta}$
$\gamma_e |B_\perp|$
$\frac{\gamma_e B_\perp}{\Delta}$
$A_\perp$
$A_x = A_y$
$S_x \sigma_x + S_y \sigma_y$
$S_+ \sigma_- + S_- \sigma_+$

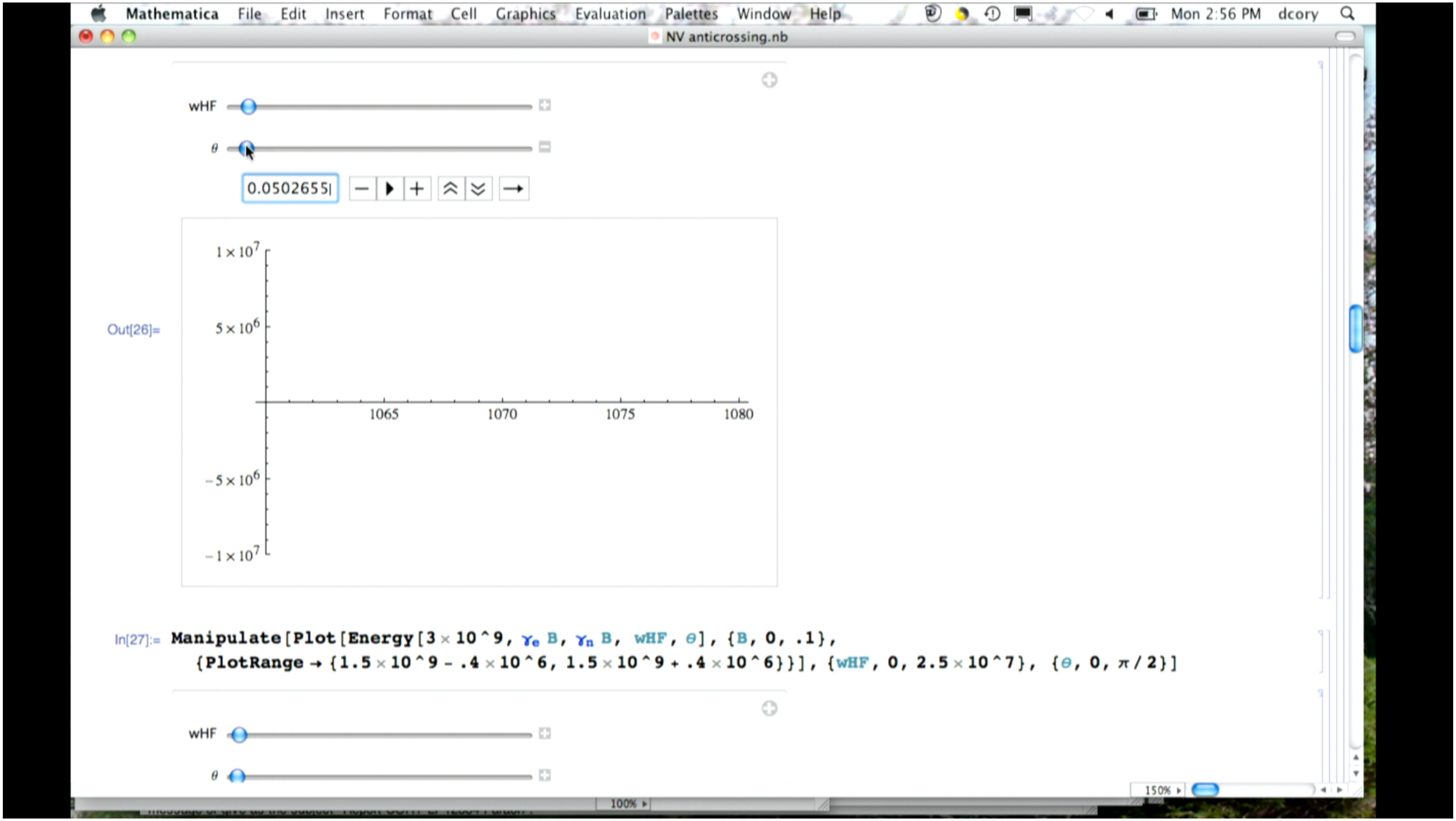


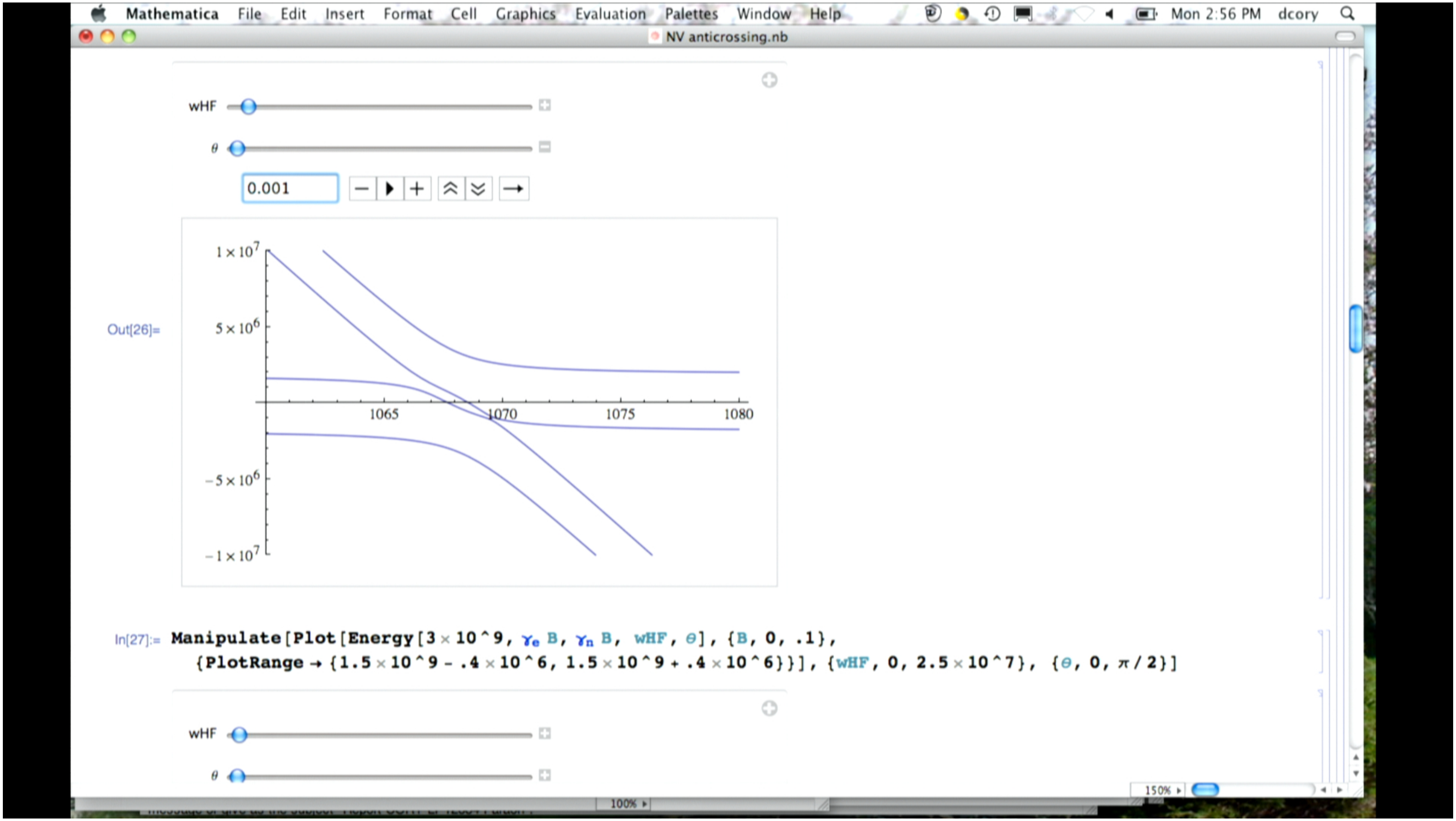
σ_{PAS}
$m_s = -1$
$+ S_y A_y'$
$-1/2$
$+1/2$
$m_s = 0$
$-1/2$
$+1/2$

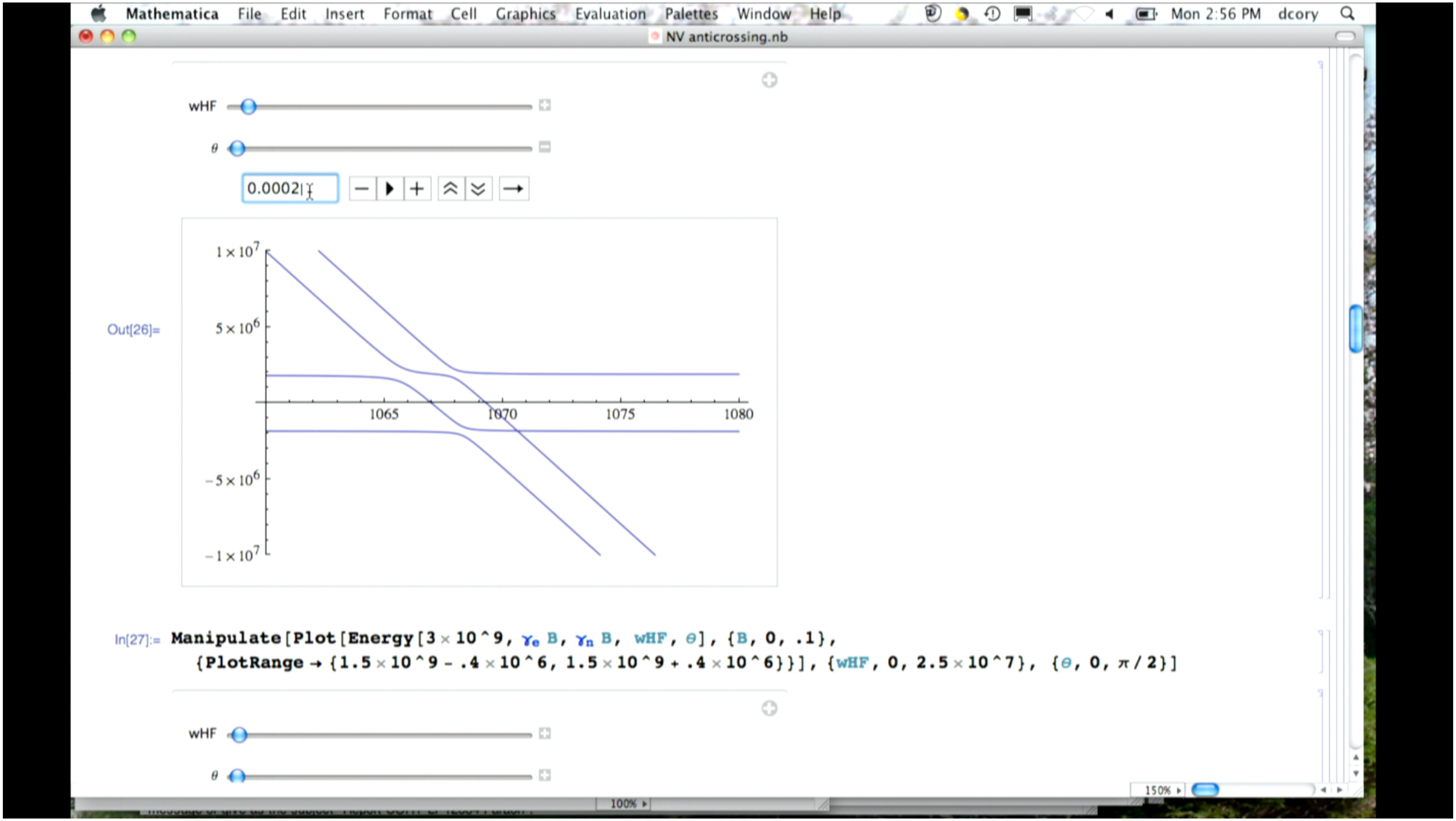


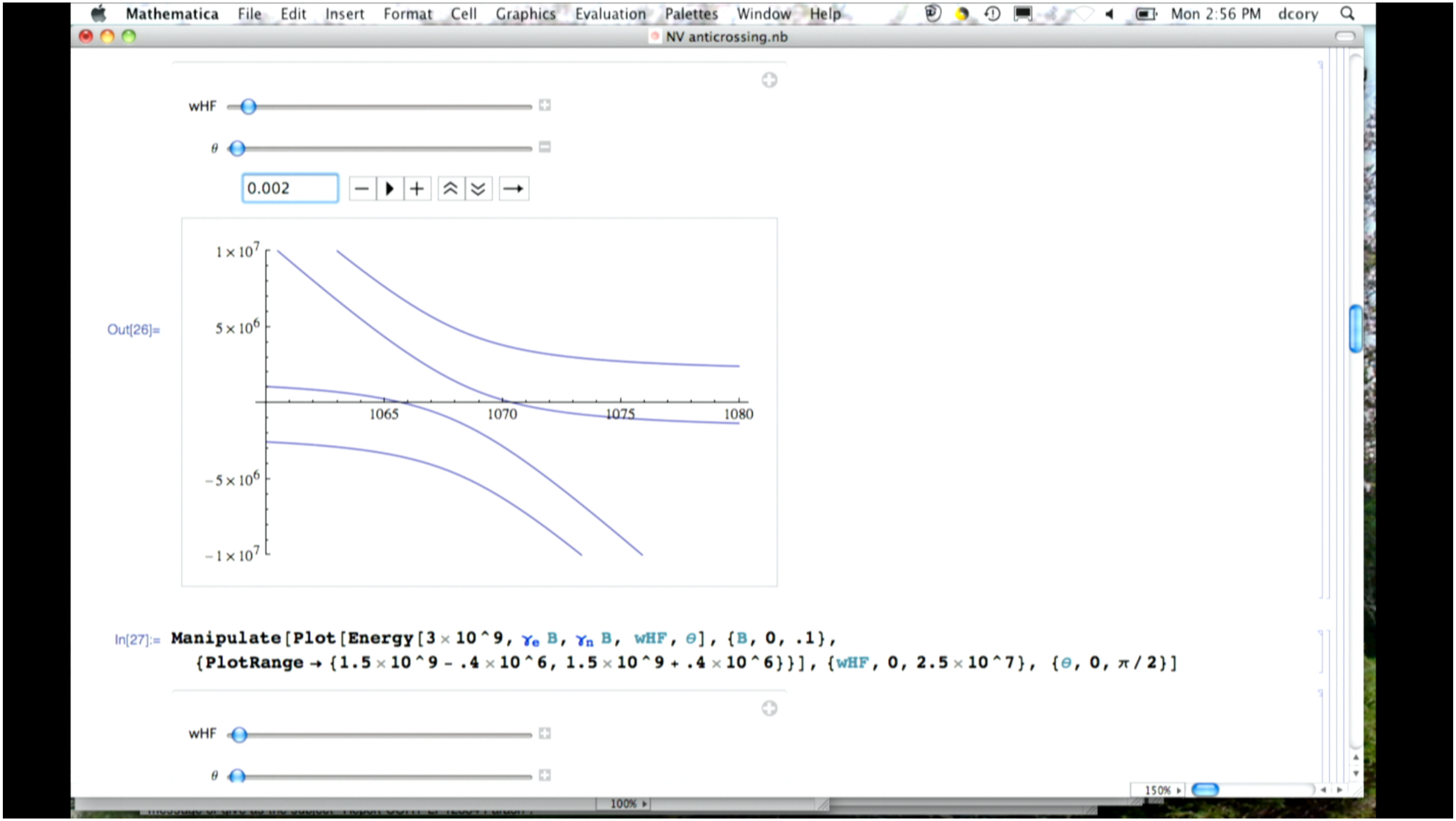
σ_{PAS}
$m_s = -1$
$+S_y A_y'$
$-1/2$
$+1/2$
$m_s = 0$
$S_- \sigma_-$

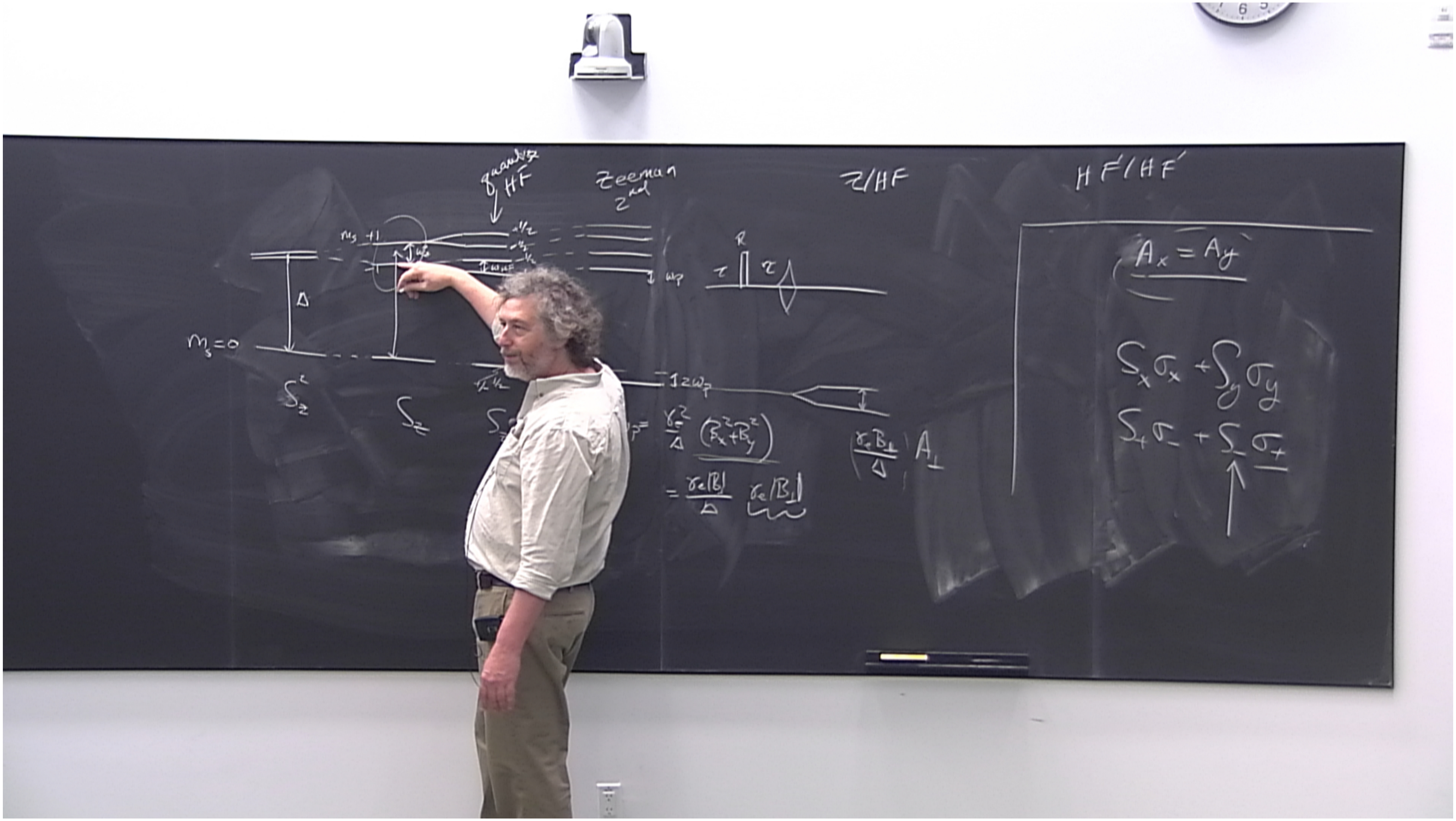

σ_{PAS}
$m_s=-1$
$+S_y A'_y$
$-1/2$
$+1/2$
$m_s=0$
$-1/2$
$+1/2$
$S_-\sigma_-$

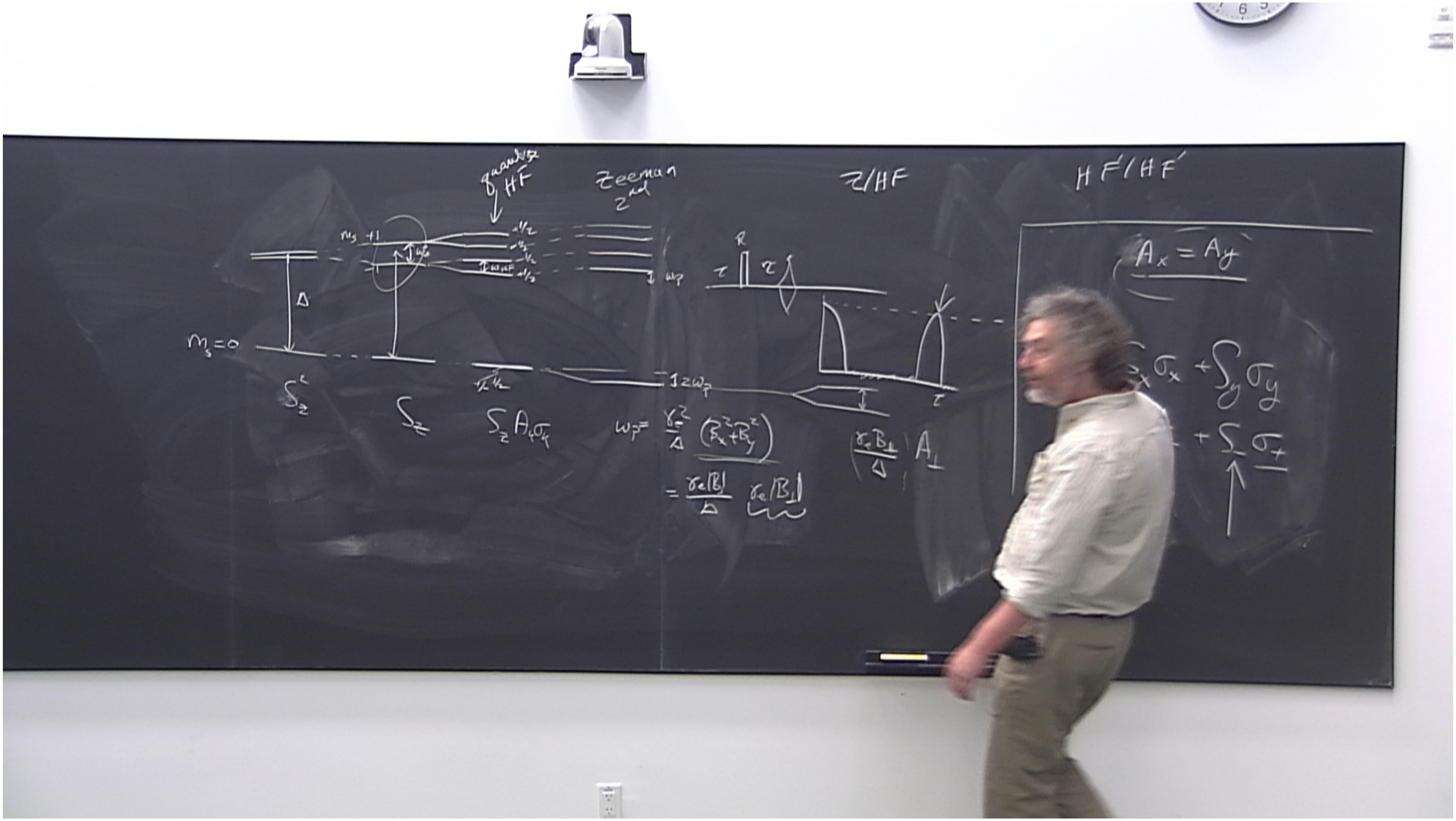

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Mon 2:56 PM dcory
NV anticrossing.nb
wHF
θ
0.0502655
Out[26]=
1 × 10^7
5 × 10^6
−5 × 10^6
−1 × 10^7
1065
1070
1075
1080
In[27]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, .1},
{PlotRange → {1.5 × 10^9 - .4 × 10^6, 1.5 × 10^9 + .4 × 10^6}}], {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
wHF
θ
150%
100%


Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Mon 2:56 PM dcory
NV anticrossing.nb
wHF
θ
0.001
Out[26]=
1 × 10^7
5 × 10^6
−5 × 10^6
−1 × 10^7
1065
1070
1075
1080
In[27]:=
Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, .1},
{PlotRange → {1.5 × 10^9 - .4 × 10^6, 1.5 × 10^9 + .4 × 10^6}}], {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
wHF
θ
150%
100%


Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Mon 2:56 PM dcory
NV anticrossing.nb
wHF
θ
0.0002
Out[26]=
1 × 10^7
5 × 10^6
−5 × 10^6
−1 × 10^7
1065
1070
1075
1080
In[27]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, .1},
{PlotRange → {1.5 × 10^9 - .4 × 10^6, 1.5 × 10^9 + .4 × 10^6}}], {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
wHF
θ
150%
100%


Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Mon 2:56 PM dcory
NV anticrossing.nb
wHF
θ
0.002
Out[26]=
1 × 10^7
5 × 10^6
−5 × 10^6
−1 × 10^7
1065
1070
1075
1080
In[27]:= Manipulate[Plot[Energy[3 × 10^9, γe B, γn B, wHF, θ], {B, 0, .1},
{PlotRange → {1.5 × 10^9 - .4 × 10^6, 1.5 × 10^9 + .4 × 10^6}}], {wHF, 0, 2.5 × 10^7}, {θ, 0, π / 2}]
wHF
θ
150%
100%





quadratic HF
Zeeman 2nd
Z/HF
HF/HF'
m_s +1
$m_s = 0$
Δ
ω_{HF}
$2\omega_p$
ω_p
τ
π
S_z^2
S_z
$S_z A_{zz} \sigma_z$
$\omega_p = \frac{\gamma_e^2}{\Delta}(B_x^2 + B_y^2)$
$= \frac{\gamma_e |B_\perp|}{\Delta} \gamma_e |B_\perp|$
$\frac{\gamma_e B_\perp}{\Delta} A_\perp$
$A_x = A_y$
$S_x \sigma_x + S_y \sigma_y$
$+ S_- \sigma_+$