

Title: Spontaneous Broken Symmetry 2B

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URL: <http://pirsa.org/07110063>

Abstract:

$$\frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle = M^*$$

$$\frac{\partial}{\partial \lambda}$$

$$C_1 = 1 + \frac{\lambda}{Z}$$

$$H_{\text{ren}} = H_{\text{int}} - M H_{\text{ext}}$$

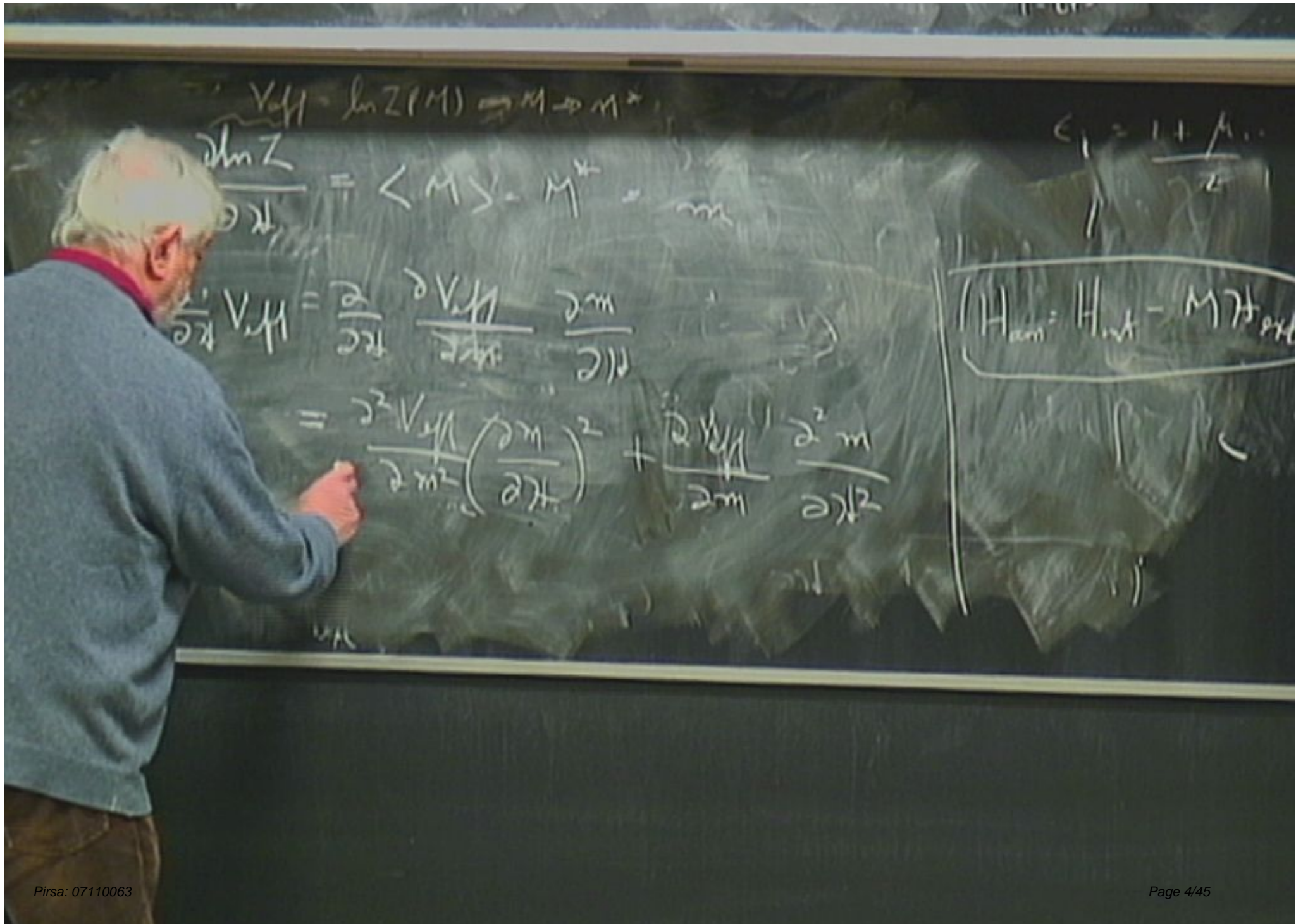
$$V_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \kappa} = \langle M \rangle = M^*$$

$$\frac{\partial V_{eff}}{\partial \kappa} = \frac{\partial \ln Z}{\partial \kappa} = \langle M \rangle = M^*$$

$$C_1 = \frac{1 + \mu}{2}$$

$$H_{rem} = H_{int} - M H_{ext}$$



$$V_{\text{eff}} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial M} = \langle M \rangle = M^*$$

$$\frac{\partial V_{\text{eff}}}{\partial M} = \frac{\partial}{\partial M} \left(\frac{1}{2} \frac{M^2}{m^2} + \frac{2}{m^2} \frac{\partial V_{\text{eff}}}{\partial M} \right) + \frac{\partial V_{\text{eff}}}{\partial M} \frac{\partial^2 M}{\partial M^2}$$

$$\epsilon = \frac{1 + \mu}{2}$$

$$H_{\text{ren}} = H_{\text{int}} - M H_{\text{ext}}$$

$$V_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \kappa} = \langle M \rangle = M^*$$

$$\frac{\partial V_{eff}}{\partial \kappa} = \frac{\partial}{\partial \kappa} \left(\frac{\partial \ln Z}{\partial \kappa} \right)$$

$$= \frac{\partial^2 V_{eff}}{\partial \kappa^2} + \frac{\partial^2 \ln Z}{\partial \kappa^2}$$

$$C_1 = \frac{1 + \mu}{2}$$

$$H_{ann} = H_{int} - M H_{ext}$$

$$V_{\text{eff}} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial K} = \langle M \rangle = M^*$$

$$\frac{\partial V_{\text{eff}}}{\partial K} = \frac{\partial}{\partial K} \left(\frac{\partial V_{\text{eff}}}{\partial M} \right) = \frac{\partial^2 V_{\text{eff}}}{\partial K \partial M}$$

$$= \frac{\partial^2 V_{\text{eff}}}{\partial M^2} \left(\frac{\partial M}{\partial K} \right)^2 + \frac{\partial^2 V_{\text{eff}}}{\partial K^2} \frac{\partial^2 M}{\partial K^2}$$

$$C = \frac{1 + \chi}{2}$$

$$H_{\text{rem}} = H_{\text{int}} - M H_{\text{ext}}$$

$$V_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle = M^*$$

$$\frac{\partial V_{eff}}{\partial \lambda} = \frac{\partial}{\partial \lambda} \left(\frac{m c}{\lambda} \right)$$

$$= \frac{\partial}{\partial \lambda} \left(\frac{m c}{\lambda} \right) + \frac{\partial}{\partial \lambda} \left(\frac{m^2 c}{2 \lambda} \right)$$

$$c = \frac{1 + \lambda}{2}$$

$$H_{tot} = H_{int} - M H_{ext}$$



$$Y_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle = M^*$$

$$\frac{\partial \langle M \rangle}{\partial \lambda} = \frac{\partial M^*}{\partial \lambda} = \frac{\partial^2 \ln Z}{\partial \lambda^2}$$

$$= \frac{1}{m} \frac{\partial^2 \ln Z}{\partial \lambda^2} + \frac{\partial^2 \ln Z}{\partial \lambda^2} \frac{1}{m}$$

$$\left(H_{ext} = H_{int} - \dots \right)$$

$$V_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \mu} = \langle M \rangle = M^*$$

$$\frac{\partial}{\partial \mu} \left(\frac{\partial \ln Z}{\partial \mu} \right) = \frac{\partial \langle M \rangle}{\partial \mu} = \frac{\partial M^*}{\partial \mu}$$

$$= \frac{\partial}{\partial \mu} \left(\frac{\partial \ln Z}{\partial \mu} \right) = \frac{\partial \langle M \rangle}{\partial \mu} = \frac{\partial M^*}{\partial \mu}$$

$$\left(H_{ann} = H_{int} \right)$$

$$Y_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \mu} = \langle M \rangle = M^*$$

$$\frac{\partial \ln Z}{\partial \mu} = \langle M \rangle = M^* \quad \left| \quad \frac{\partial \ln Z}{\partial \mu} = \langle M \rangle = M^* \right.$$

$$\frac{\partial^2 \ln Z}{\partial \mu^2} = \langle M^2 \rangle - \langle M \rangle^2 = \chi$$

$$\frac{\partial^2 \ln Z}{\partial \mu^2} = \chi$$

$$\frac{\partial^2 \ln Z}{\partial \mu^2} = \chi$$



$$Y_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle = M^*$$

$$\frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle = M^* \quad \frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle = M^*$$

$$= \frac{\partial^2 \ln Z}{\partial \lambda^2} + \frac{\partial^2 \ln Z}{\partial \lambda^2}$$

$$\frac{\partial^2 \ln Z}{\partial \lambda^2}$$

$$\ln H_{ann} = \ln H_{int}$$

$$Y_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \mu} = \langle M \rangle = M^*$$

$$\frac{\partial \ln Z}{\partial \mu} = \langle M \rangle = M^*$$

$$= \frac{\partial}{\partial \mu} \left(\frac{m^2}{2\mu} \right) + \frac{\partial}{\partial \mu} \left(\frac{m^2}{2\mu} \right)$$

$$\frac{m^2}{2\mu} = \chi$$

$$H_{ann} = H_{int}$$

$$\text{Yaff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \mu} = \langle M \rangle - M^*$$

$$\frac{\partial \ln Z}{\partial \mu} = \langle M \rangle - M^* \quad \left| \quad \frac{\partial \ln Z}{\partial \mu} = \langle M \rangle - M^* \right.$$

$$\frac{\partial^2 \ln Z}{\partial \mu^2} = \langle M^2 \rangle - 2M^* \langle M \rangle + (M^*)^2$$

$$H_{\text{ann}} = H_{\text{int}}$$

$$\frac{\partial \ln Z}{\partial h}$$

$$\frac{\partial h}{\partial h}$$

$\langle \mu \rangle$

\rangle

μ



$$\chi_{\mu} = \frac{\partial \ln Z}{\partial \mu}$$
$$T > T_c$$

Modified spin theory

$$\frac{\partial \ln Z}{\partial h}$$

$$\frac{\partial \ln Z}{\partial h}$$

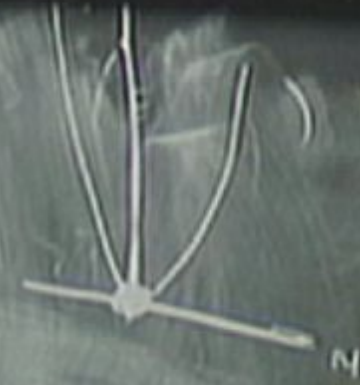
$$\frac{\partial \ln Z}{\partial h_i} = \langle \sigma_i \rangle$$

$$\frac{\partial \langle \sigma_i \rangle}{\partial h_i} = \langle \sigma_i^2 \rangle - \langle \sigma_i \rangle^2$$

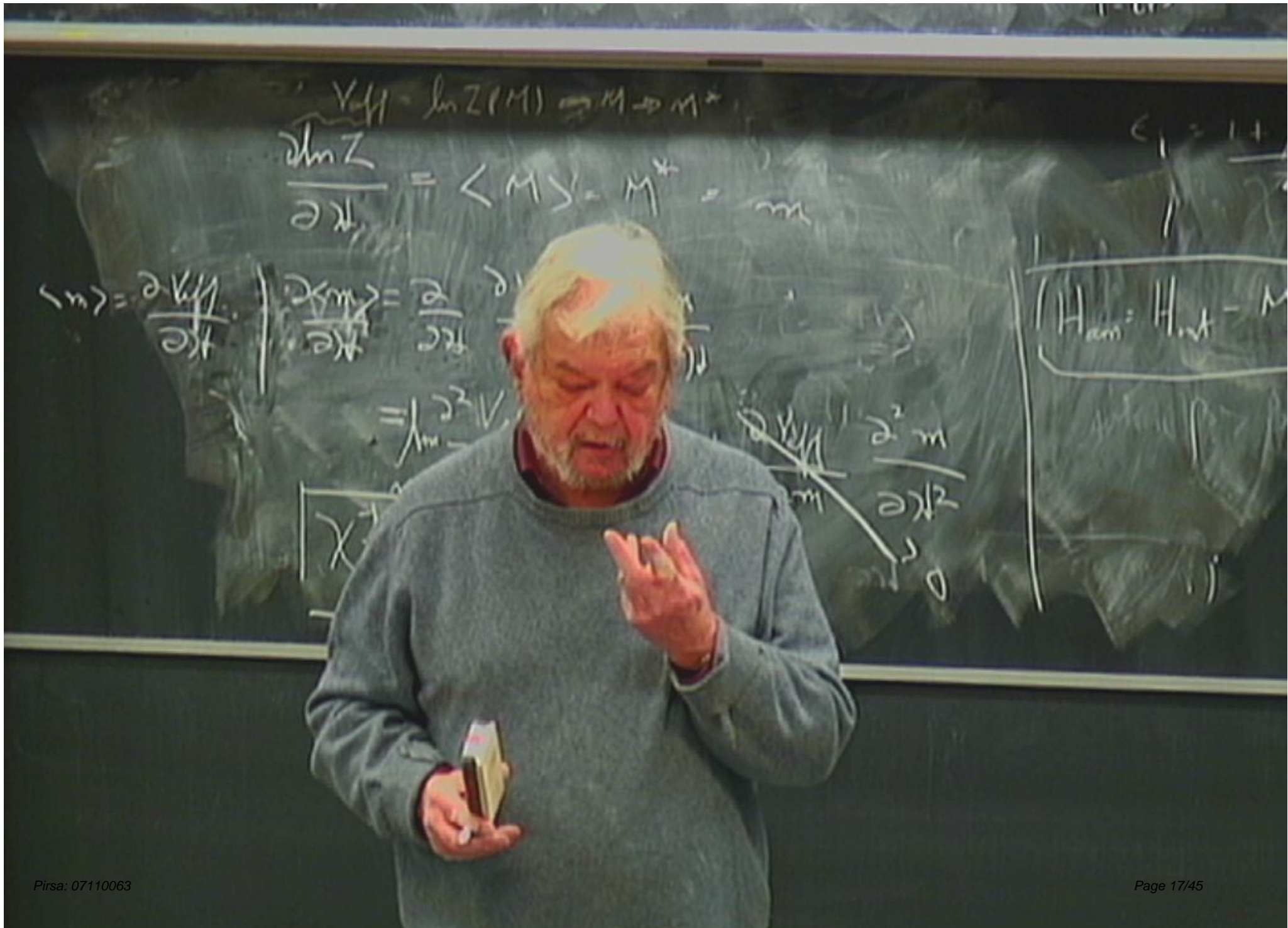
Modified spin theory

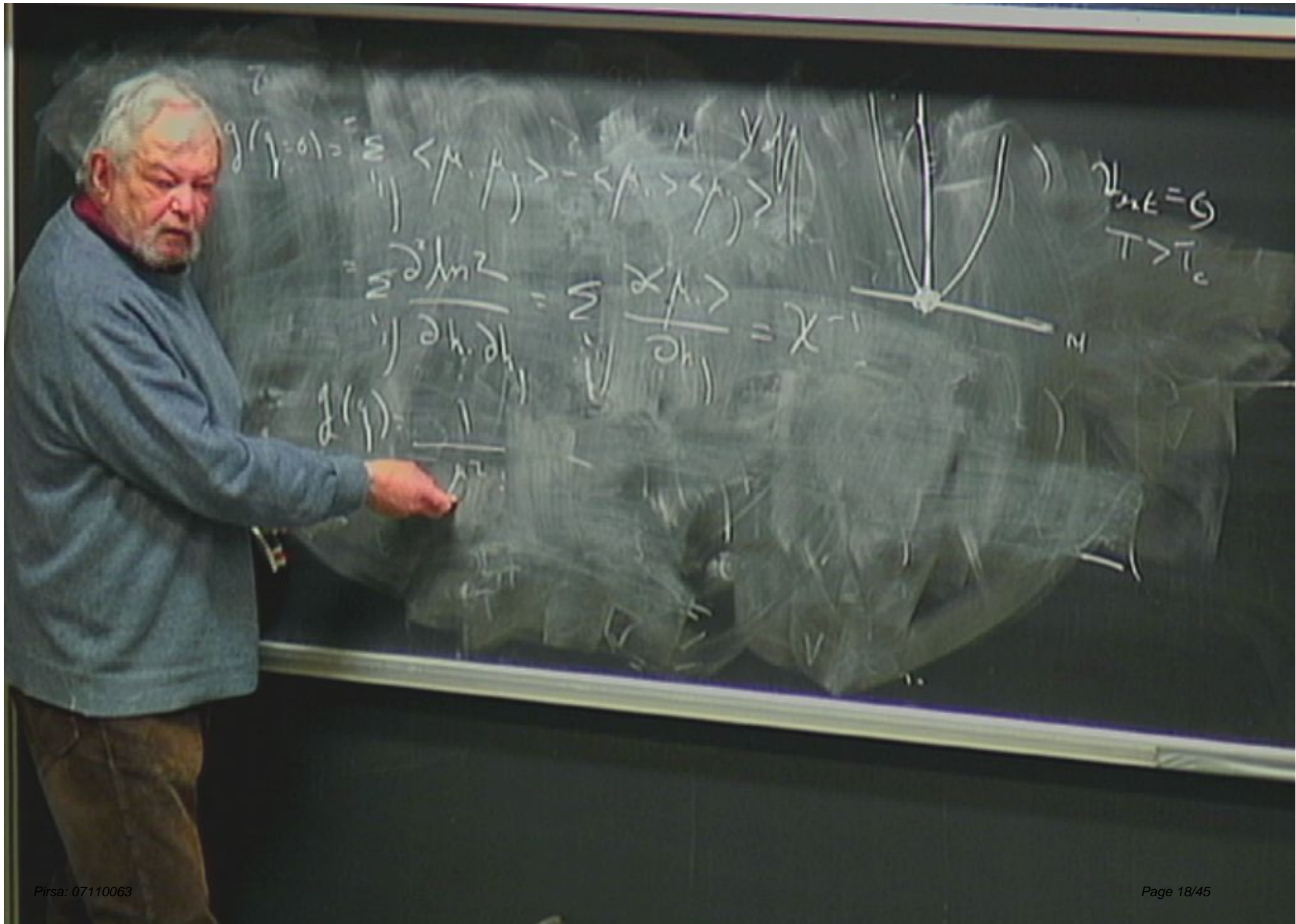
$$J_{ij} = \frac{\partial \langle \sigma_i \rangle}{\partial h_j}$$

$$\chi_{ij} = \frac{\partial \langle \sigma_i \rangle}{\partial h_j}$$



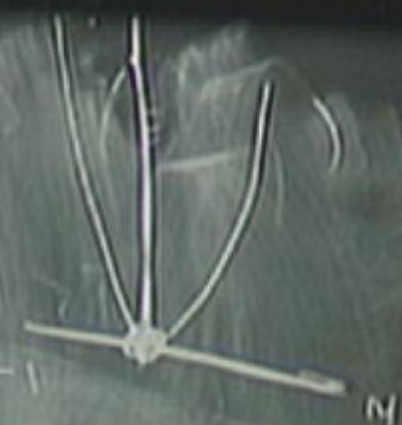
$$\chi_{ij} = \chi_{ji}$$
$$T > T_c$$





$$g(\gamma=0) = \sum \langle \mu_i \mu_j \rangle - \langle \mu_i \rangle \langle \mu_j \rangle$$

$$= \sum \frac{\partial^2 \ln Z}{\partial h_i \partial h_j} = \sum \frac{\partial \langle \mu_i \rangle}{\partial h_j} = \chi^{-1}$$

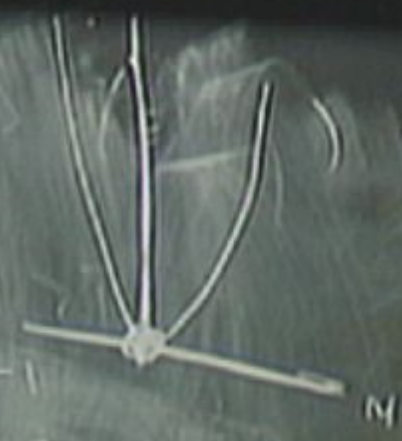


$\chi_{\mu_i} = 0$
 $T > T_c$

$$g(\eta=0) = \sum \langle \mu_i \mu_j \rangle - \langle \mu_i \rangle \langle \mu_j \rangle$$

$$= \sum \frac{\partial^2 \ln Z}{\partial h_i \partial h_j} = \sum \frac{\partial \langle \mu_i \rangle}{\partial h_j} = \chi^{-1}$$

$$g(\eta) = \frac{1}{\chi^2}$$



$\chi_{\eta E} = 0$
 $T > T_c$

$$V_{eff} = \ln Z(M) \Rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial M} = \langle M \rangle = M^*$$

$$\frac{\partial^2 \ln Z}{\partial M^2} = \frac{\partial}{\partial M} \left(\frac{\partial \ln Z}{\partial M} \right) = \frac{\partial \langle M \rangle}{\partial M} = \frac{\partial \langle M \rangle}{\partial \ln Z} \frac{\partial \ln Z}{\partial M} = \frac{\partial \langle M \rangle}{\partial \ln Z} M^*$$

$$= \frac{1}{M^*} \left(\frac{\partial \langle M \rangle}{\partial \ln Z} \right) M^* = \frac{\partial \langle M \rangle}{\partial \ln Z}$$

$$\frac{\partial^2 \ln Z}{\partial M^2} = \chi$$

$$H_{max} = H_{min}$$

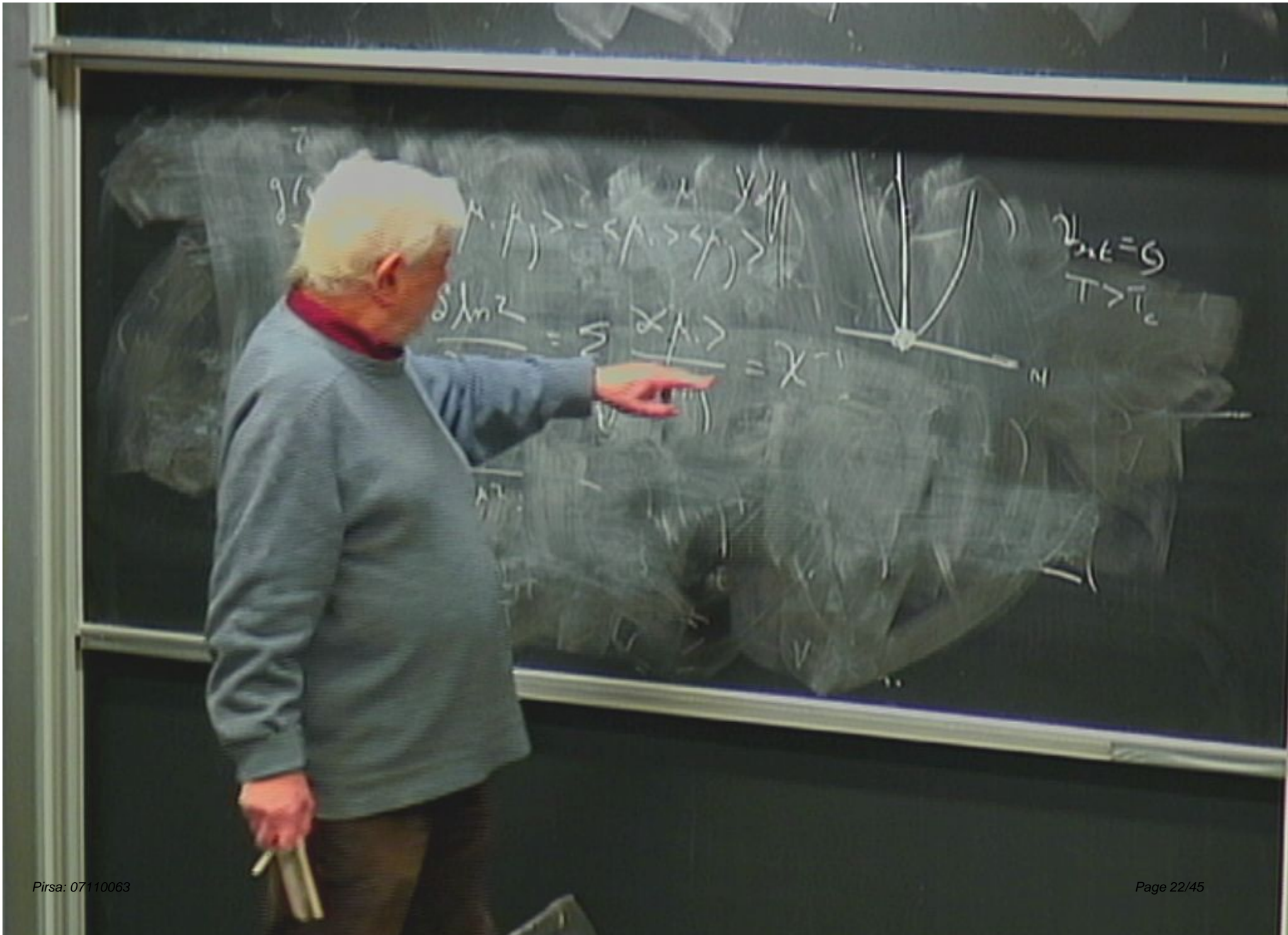
$$Y_{eff} = \ln Z(M) \rightarrow M \rightarrow M^*$$

$$\frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle - M^*$$

$$\frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle - M^* \quad \left| \quad \frac{\partial \ln Z}{\partial \lambda} = \langle M \rangle - M^* \right.$$

$$\frac{\partial^2 \ln Z}{\partial \lambda^2} = \langle M^2 \rangle - M^2$$

$$H_{ann} = H_{int}$$

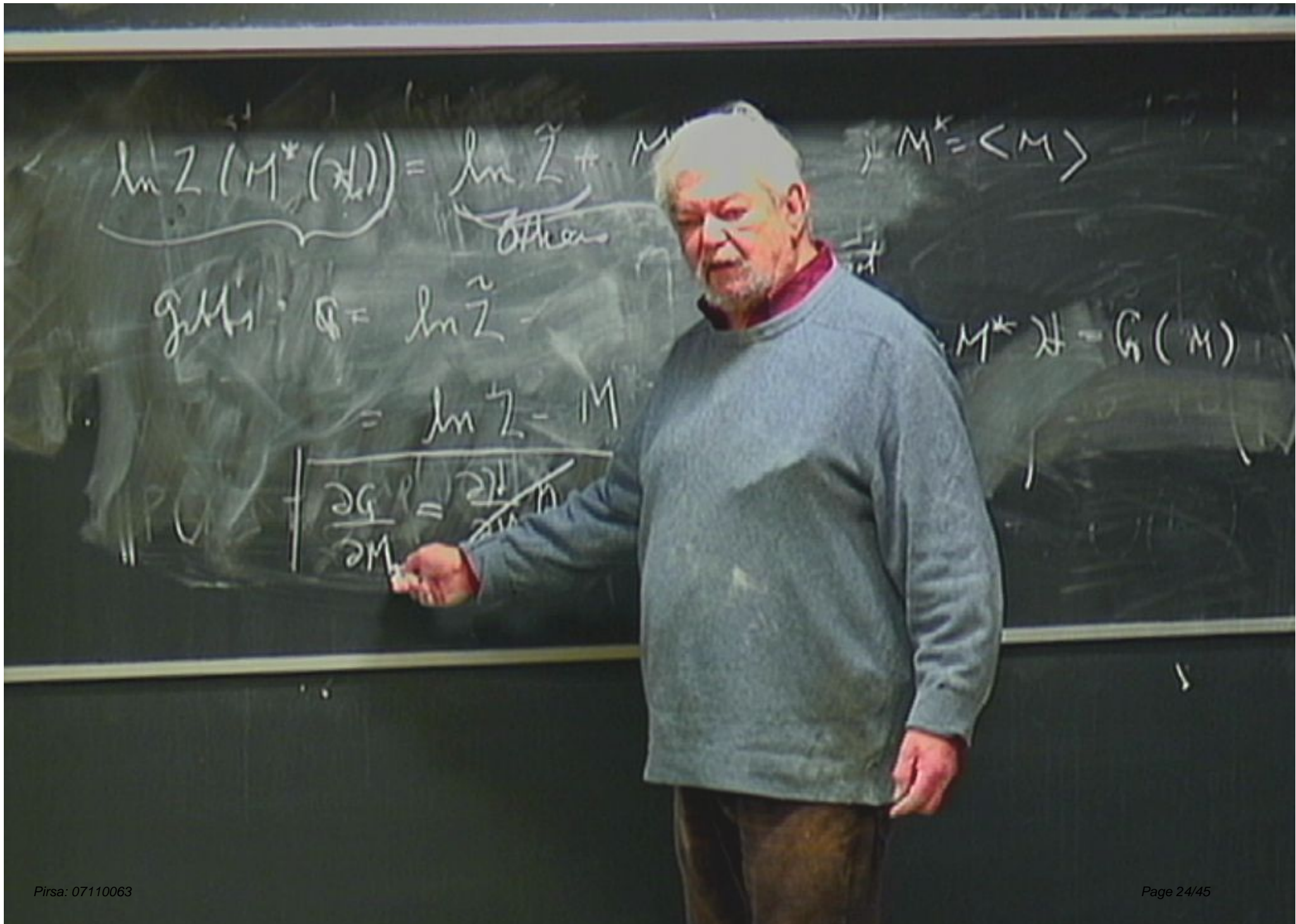


$$\ln Z(M^*(\lambda)) = \ln \tilde{Z} + M^* \mathcal{H}_{\text{int}} \quad ; \quad M^* = \langle M \rangle$$

gibbs: $Q = \ln \tilde{Z}$

$$= \ln \tilde{Z} - M \mathcal{H}_{\text{int}}$$

$$Z \rightarrow M^* \mathcal{H} = G(M)$$



$$\ln Z(M^*(\lambda)) = \ln \tilde{Z} + M^* \quad ; \quad M^* = \langle M \rangle$$

Others

Zellen: $G = \ln \tilde{Z}$

$$= \ln \tilde{Z} - M$$

$$M^* H = G(M)$$

$\frac{\partial G}{\partial M} = \frac{\partial H}{\partial M}$

$$\ln Z(M^*(\lambda)) = \underbrace{\ln \tilde{Z}}_{\text{other}} + M^* \lambda_{\text{int}} \quad M^* = \langle M \rangle$$

gibbs: $G = \ln \tilde{Z}$

$$= \ln \tilde{Z} - M \lambda_{\text{int}}$$

$G(M)$

$$\left| \frac{\partial G}{\partial M} = \frac{\partial \ln \tilde{Z}}{\partial M} - \lambda_{\text{int}} \right|$$



$$g(\eta=0) = \sum_{i,j} \langle \mu_i \mu_j \rangle - \langle \mu_i \rangle \langle \mu_j \rangle$$

$$= \sum_{i,j} \frac{\partial^2 \ln Z}{\partial h_i \partial h_j} = \sum_{i,j} \frac{\partial \chi_i}{\partial h_j} = \chi^{-1}$$

$$g(\eta) = \frac{1}{\chi}$$



$T < T_c$



$T > T_c$

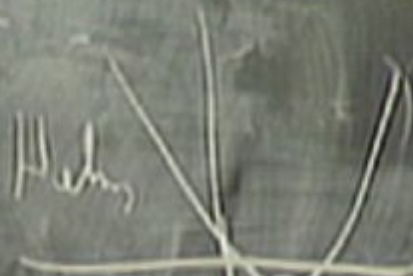
$$g(\rho=0) = \sum_{i,j} \langle \mu_i \mu_j \rangle - \langle \mu_i \rangle \langle \mu_j \rangle$$

$$= \sum_{i,j} \frac{\partial^2 \ln Z}{\partial h_i \partial h_j} = \sum_{i,j} \frac{\partial \langle \mu_i \rangle}{\partial h_j} = \chi^{-1}$$

$$g(\rho) = \frac{1}{\chi^2}$$



$\chi_{\mu E} = 0$
 $T > T_c$



$\chi_{\mu E} > 0$



$$g(\eta=0) = \sum_{ij} \langle \mu_i \mu_j \rangle - \langle \mu_i \rangle \langle \mu_j \rangle$$

$$= \sum_{ij} \frac{\partial^2 \ln Z}{\partial h_i \partial h_j} = \sum_{ij} \frac{\partial \langle \mu_i \rangle}{\partial h_j} = \chi^{-1}$$

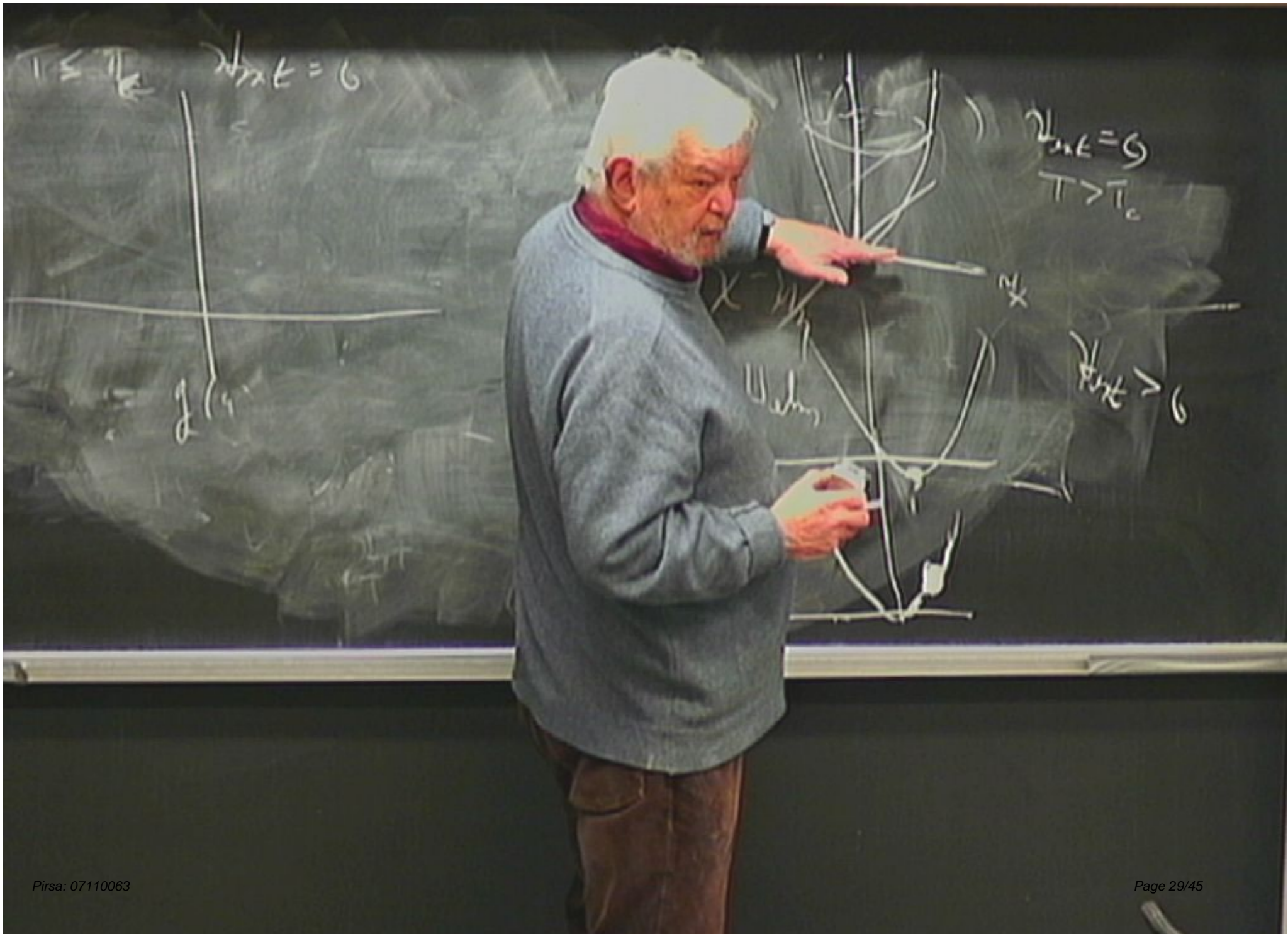
$$g(\eta) = \frac{1}{\mu^2}$$



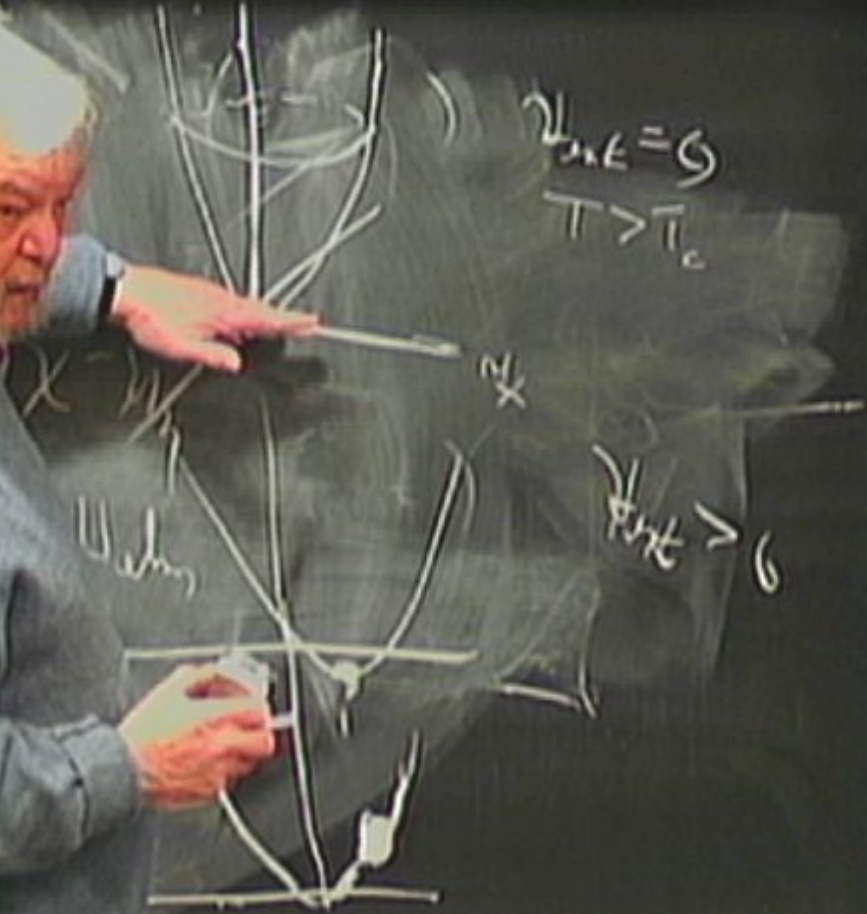
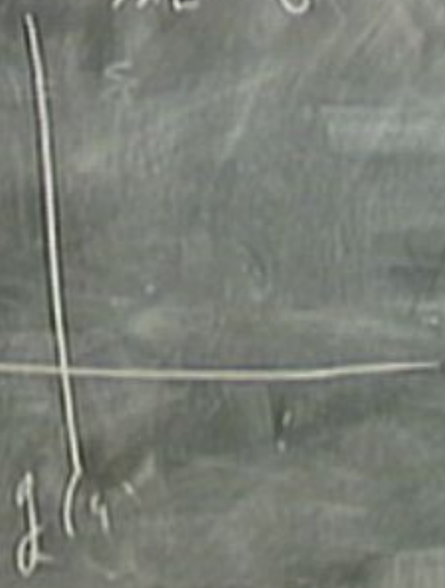
$T < T_c$



$T > T_c$

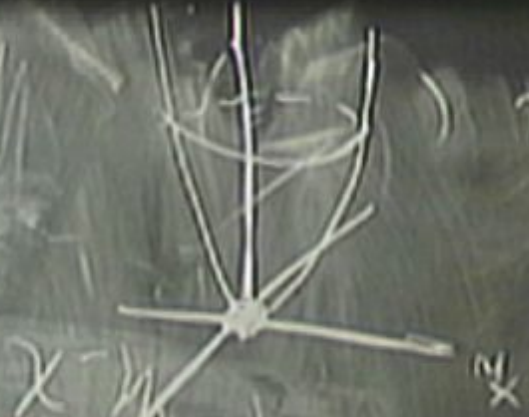
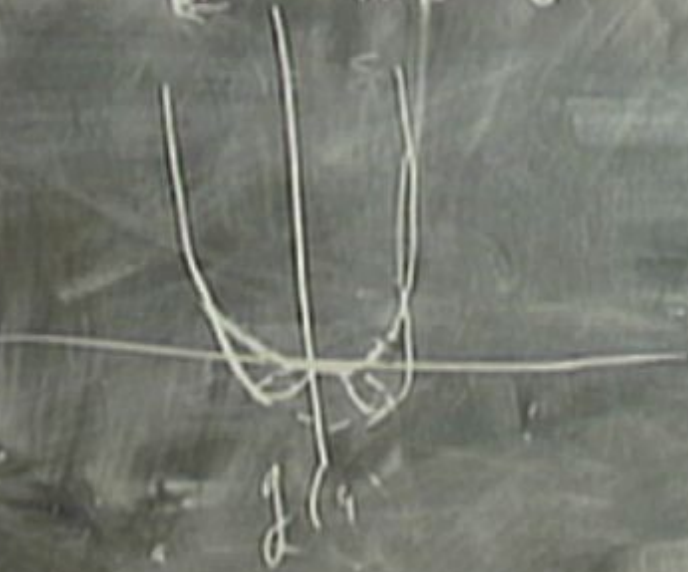


$$T \leq T_c \quad \frac{dH}{dT} = 0$$



$$T \leq T_c$$

$$\Delta H_{mE} = 0$$



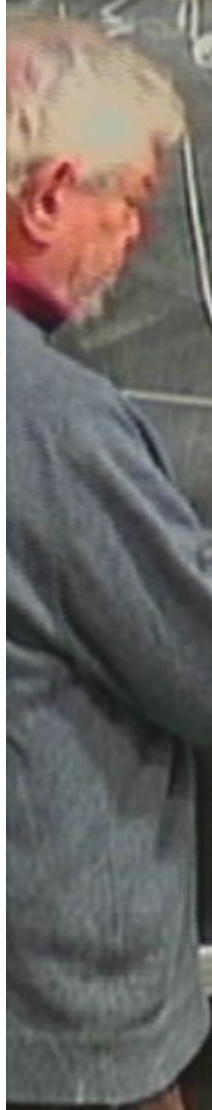
$$\Delta H_{mE} = 0$$

$$T > T_c$$



$$\Delta H_{mE} > 0$$





$\mu_{HE} = 0$

$T > T_c$

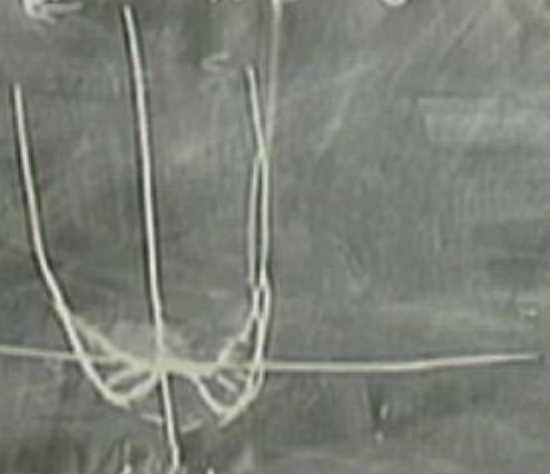
$\mu_{HE} > 0$

Helium

χ_{IT}

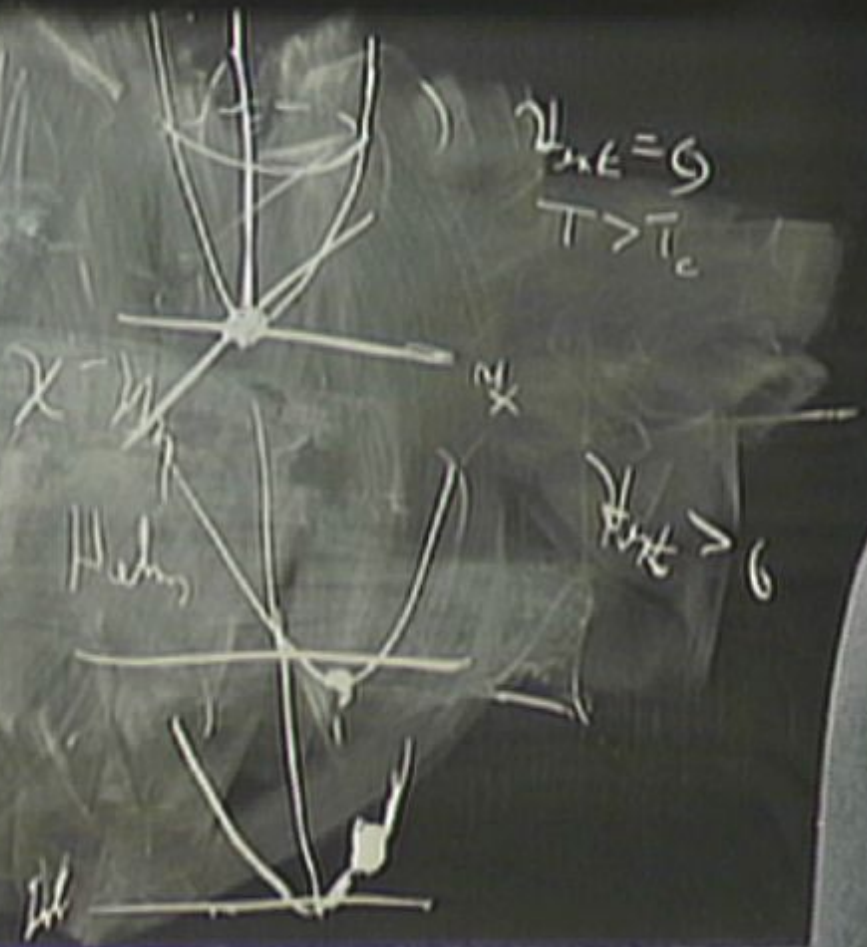
χ_{IIII}

$T \leq T_c$ $\Delta_{max} = 0$



Max destroyed χ_{IT}

χ_{IT}

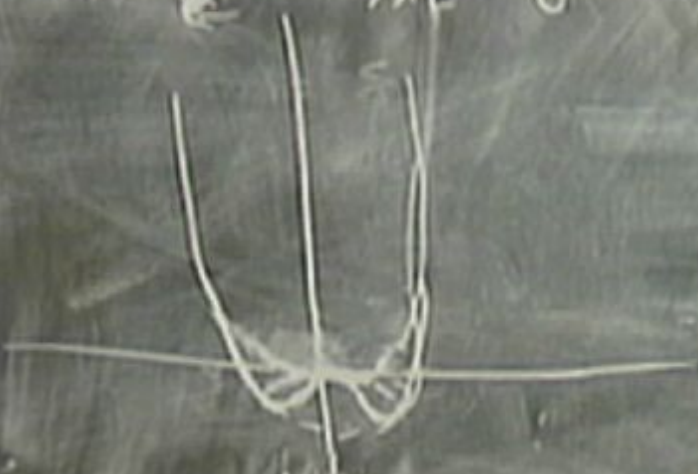


$\Delta_{max} = 0$
 $T > T_c$

Helm

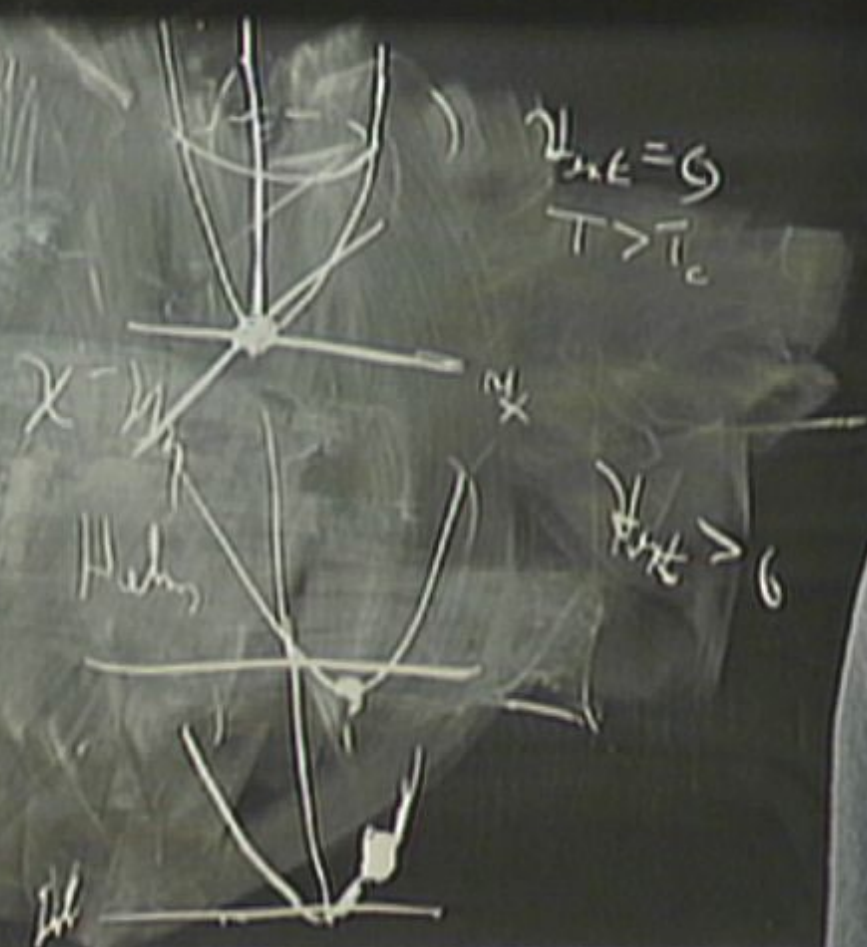
$\Delta_{max} > 0$

$T \leq T_c$ $\Delta_{max} = 0$



Most distinctive χ_{IT}

χ_{IT}



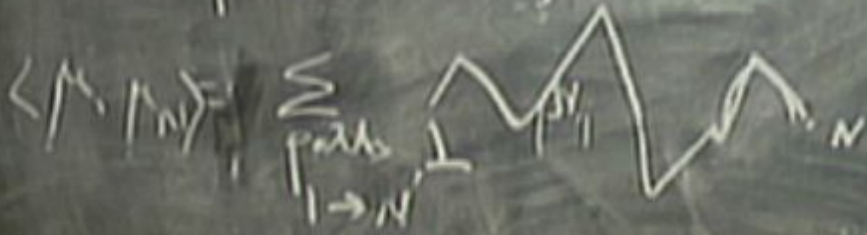
Helm

$$H_{xyt} = 0 \quad (\langle M \rangle = 0 \quad T \gg T_c)$$

$$\langle g_{ij} \rangle = S_{ij} + \dots$$

$$g(\gamma) = \frac{1}{1 - \tilde{\rho}(\gamma)} \approx \frac{1}{1 - \tilde{\rho}(0)} \approx \frac{1}{\sqrt{M^2 + T^2}}$$

$$\langle \ln g(\gamma) \rangle = \sum_{j=1}^N \langle \ln \mu_j \rangle \sim \frac{1}{N} \sum_{j=1}^N \langle \ln \mu_j \rangle$$



$$\langle T \rangle = \dots$$

$$X = \frac{v_A}{c}$$

k bit protocol
 share $k+1$ vectors λ_i
 send $\sum_{i=1}^n (a \cdot \lambda_i)$

$\beta \in V, \mu, \nu$
 $\int_{\infty} \{ \phi \}$
 $(1 - \rho_{\text{info}})^2$
 $\frac{1}{\nu^2}$
 (ν)
 $1 - \epsilon^2$

k bit protocol
 share $k+1$ vectors λ_k
 send $\text{sum}(\hat{a} \cdot \lambda_i)$
 $\lambda_1 \cdot \lambda_1 = 0$
 $n = 4$

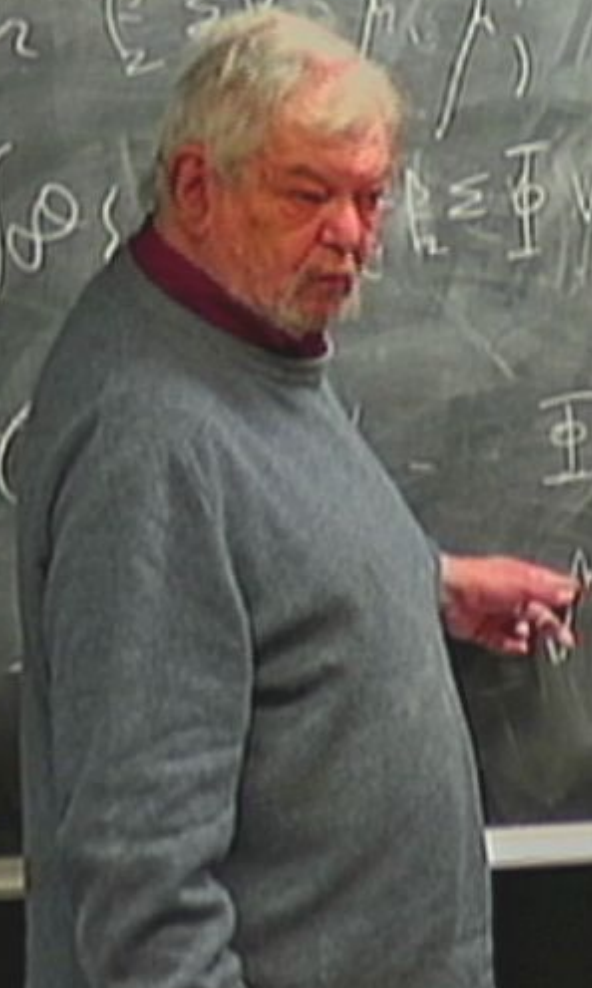
$$Z = \frac{1}{2} \left(\sum_{i=1}^n s_i \cdot \lambda_i \right)$$

$$= \int_{\mathcal{D}} \left(\sum_{i=1}^n \phi_i \cdot \lambda_i \right)$$

$$\mathcal{D} = \phi_1 \dots \phi_n$$

$$\lambda = \lambda_1 \dots \lambda_n$$

$(1 - \rho \cdot \lambda_0)^2$
 $\frac{1}{\sqrt{2}}$
 (2)



$$Z = \int \mathcal{D}\phi \exp\left(-\beta \sum_i \left[\frac{1}{2} \phi_i^T V \phi_i + \mu \phi_i \right]\right)$$

$$= \int \mathcal{D}\phi \exp\left(-\beta \sum_i \left[\frac{1}{2} (\phi_i - \mu^{-1} V \phi_i)^T V (\phi_i - \mu^{-1} V \phi_i) + \mu \phi_i \right]\right)$$

$$\phi_i = \phi_1, \dots, \phi_N$$

$$\mu = \mu_1, \dots, \mu_N$$

$$Z = \int \mathcal{D}\phi \exp(-\int d^4x \mathcal{L}(\phi, \partial\phi))$$

$$\int \mathcal{D}\phi \exp(-\int d^4x \mathcal{L}(\phi, \partial\phi)) = \int \mathcal{D}\phi_1 \dots \mathcal{D}\phi_N \exp(-\int d^4x \mathcal{L}(\phi_1, \dots, \phi_N, \partial\phi_1, \dots, \partial\phi_N))$$

$$\int \mathcal{D}\phi = \int \mathcal{D}\phi_1 \dots \mathcal{D}\phi_N$$

$$\int \mathcal{D}\phi = \int \mathcal{D}\phi_1 \dots \mathcal{D}\phi_N$$

$$Z = \int \mathcal{D}\phi \exp(-\int d^4x \mathcal{L}(\phi, \partial\phi))$$

$$= \int \mathcal{D}\phi \exp(-\int d^4x \left[\frac{1}{2} \partial_\mu \phi \partial^\mu \phi + V(\phi) \right])$$

$$\mathcal{D}(\phi) = \prod_{\mathbf{x}} d\phi_{\mathbf{x}} \quad \mathcal{L} = \mathcal{L}_K + \mathcal{L}_V$$

$$\begin{aligned} \mathcal{L}_K &= \frac{1}{2} \partial_\mu \phi \partial^\mu \phi \\ \mathcal{L}_V &= V(\phi) \end{aligned}$$

$$Z = \frac{1}{h} \left(\sum_{\nu} \sum_{i} v_{i\nu} \right) / (kT)$$

$$= \int \rho(\phi) \left(\frac{1}{h} \sum_{i} \int_{\nu} v_{i\nu} \right) d\phi$$

$$Z = \frac{1}{h} \left(\sum_i e^{-\beta \epsilon_i} \right)$$

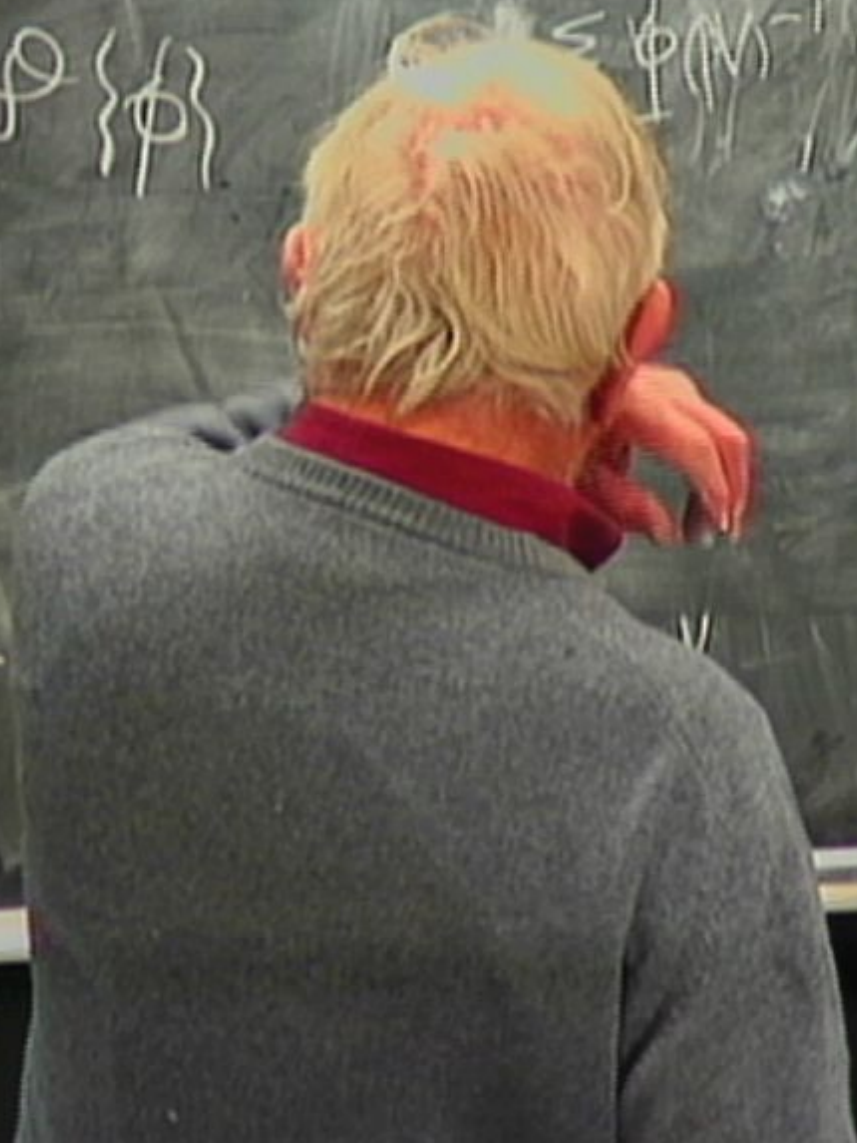
$$= \frac{1}{h} \sum_i e^{-\beta \epsilon_i} e^{-\beta \epsilon_i} e^{\beta \epsilon_i} = \frac{1}{h} \sum_i e^{-\beta \epsilon_i} e^{\beta \epsilon_i} e^{-\beta \epsilon_i}$$

$$= \sum_i \cos \phi_i$$

1-cr36

$$Z = \int \mathcal{D}\phi \exp \left[-\int d^4x \left(\frac{1}{2} \partial_\mu \phi \partial^\mu \phi + \frac{1}{2} m^2 \phi^2 + \mathcal{L}_{int}(\phi) \right) \right]$$

$$= \int \mathcal{D}\phi \exp \left[-\frac{1}{2} \int d^4x \phi(x) \Delta \phi(x) + \int d^4x \mathcal{L}_{int}(\phi) \right]$$



$$Z = \frac{1}{h} \int \prod_i \exp \left(-\beta \sum_i V_i \right) \prod_i d\phi_i$$

$$= \int \prod_i \{ \phi_i \} \exp \left(-\beta \sum_i \ln \cos \phi_i \right)$$

$$Z = \int \mathcal{D}\phi \exp\left(-\frac{1}{2} \sum_i \phi_i (M_i)^{-1} \phi_i\right) \exp\left(\sum_i \ln \cos \phi_i\right)$$

$$= \int \mathcal{D}\phi \exp\left(-\frac{1}{2} \sum_i \phi_i (M_i)^{-1} \phi_i\right) \exp\left(\sum_i \ln \cos \phi_i\right)$$

$$Z = \frac{1}{h} \int \sum_{\mathbf{v}_i} \mu(\mathbf{v}_i)$$

$$= \int \mathcal{D}\{\phi\} \exp \left[-\frac{1}{2} \sum_i \Phi^T M^{-1} \Phi \right] \exp \sum_i \ln \cos \phi_i$$

$1 - \cos^2$