

Title: String Theory Review-4

Date: Jan 29, 2015 10:15 AM

URL: <http://pirsa.org/15010065>

Abstract:

$$L_n |PHYS\rangle = 0$$

$$T(s) = -\frac{1}{24} + \sum_n L_n e^{-ns}$$

$$s = \gamma - i\sigma$$

$$\gamma = it$$

a_n, \bar{a}_n

$$[a_n, a_{-n}] = n$$

$$[\bar{a}_n, \bar{a}_{-n}] = n$$

$$[x, p] = i$$

$$[a_n, a_{-n}] = n$$

$$[\bar{a}_n, \bar{a}_{-n}] = n$$

$$[x, p] = i$$

$$\bar{a}_n |p\rangle = 0 \quad n > 0$$

$$\langle p | \bar{a}_n, \langle p | a_n, \dots, \bar{a}_{-1} | p \rangle$$

$$\langle p | a_n = 0 \quad n < 0$$

$$\langle p | \bar{a}_n = 0 \quad n < 0$$

$$\langle p | p' \rangle = \delta(p - p')$$

$$\langle p | a_{-1} | p' \rangle = 0$$

$$\langle p | a_1 a_{-1} | p' \rangle = \delta(p - p')$$

$$[a_n, a_{-n}]$$

$$[\bar{a}_n, \bar{a}_{-n}] = n$$

$$[x, p] = i$$

$$\langle p |, \langle p |$$

$$\langle p | \bar{a}_1$$

$$\langle p | a_n = 0 \quad n < 0$$

$$\langle p | \bar{a}_n = 0 \quad n < 0$$

$$a_0 = p$$

$$\bar{a}_0 = p - p$$

$$\langle p | p' \rangle = \delta(p - p')$$

$$\langle p | a_{-1} | p' \rangle = 0$$

$$\langle p | a_1 a_{-1} | p' \rangle = \delta(p - p')$$

$$i\partial_{\bar{z}} X = p + \sum_{n \neq 0} a_n e^{-ns}$$

$$-i\partial_z X = -p + \sum_{n \neq 0} \bar{a}_n e^{-n\bar{s}}$$

$$[L_n, L_m] = (n-m)L_{n+m} + \frac{c}{12}n(n^2-1)\delta_{n,0}$$

$$L_n |P\rangle = 0 \quad n > 0$$

$$\langle P | L_n = 0 \quad n < 0$$

$$L_{-1} |P\rangle = p a_{-1} |P\rangle$$

$$L_1 L_{-1} |P\rangle = p^2 |P\rangle$$

$$L_n |PHYS\rangle = 0 \quad n > 0$$

$$(L_0 - 1) |PHYS\rangle = 0$$

$$T(s) = -\frac{c}{24} + \sum_n L_n e^{-ns}$$

$$S = \tau - i\sigma$$

$$\tau = it$$

$$D = 26 = c$$

$$(25, 1)$$

$$L_n |PHYS\rangle = 0 \quad n > 0$$

$$(L_0 - 1) |PHYS\rangle = 0$$

$$\langle PHYS | L_n \quad n < 0$$

$$|NULL\rangle = L_n | \rangle' \quad n < 0$$

$$\mathcal{H}_{STRING} = \frac{\{ |PHYS\rangle \}}{\{ |NULL\rangle \} \cap \{ |PHYS\rangle \}}$$

$$T(s) = -\frac{1}{24} + \sum_n L_n e^{-ns}$$

$$S = T - i\sigma$$

$$T = it$$

$$D = 26 = c$$

$$(25, 1)$$

$$L_n |PHYS\rangle = 0 \quad n > 0$$

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$$H_{STRING} = \frac{\{ |PHYS\rangle \}}{\{ |NULL\rangle \cap |PHYS\rangle \}}$$

$$T(s) = -\frac{1}{24} + \sum_n L_n e^{-ns}$$

$$S = T - i\sigma$$

$$T = it$$

$$D = 26 = c$$

$$(25, 1)$$

$$L_n |P\rangle = 0 \quad n > 0$$

$$\langle P | L_n = 0 \quad n < 0$$

$$|P\rangle \quad P_{\frac{1}{2}}^2 = 1 \quad P^2 = 2$$

$$L_n |PHYS\rangle = 0 \quad n > 0$$

$$(L_0 - 1) |PHYS\rangle = 0$$

$$\langle PHYS | L_n \quad n < 0$$

$$|NULL\rangle = L_n | \rangle \quad n < 0$$

$$\mathcal{H}_{STRING} = \frac{\{ |PHYS\rangle \}}{\{ |NULL\rangle \} \cap \{ |PHYS\rangle \}}$$

$$\begin{aligned} \bar{L}_m |PHYS\rangle &= 0 \\ (\bar{L}_0 - 1) |PHYS\rangle &= 0 \end{aligned} \quad n > 0$$

$$T_{SS}(s) = -\frac{1}{2\alpha'} + \sum_n L_n e^{-ns}$$

$$S = \tau - i\sigma$$

$$\tau = it$$

$$D = 26 = c$$

$$(2S, 1)$$

$$T_{SS} = \dots \bar{L}_n$$

$$\epsilon_{\mu\nu} a_{-1}^{\mu} \bar{a}_{-1}^{\nu} |P\rangle$$

$$\epsilon_{\mu\nu} p^{\mu} = 0 \quad \epsilon_{\mu\nu} p^{\nu} = 0$$

$$\text{NULL } \epsilon_{\mu\nu} = p_{\mu} u_{\nu} + \bar{u}_{\mu} p_{\nu}$$

$$L_1 \epsilon_{\mu\nu} a_{-1}^{\mu} \bar{a}_{-1}^{\nu} |P\rangle$$

$$p^2 = 0$$

$$L_{-1} (u_{\mu} \bar{a}_{-1}^{\mu})$$

$$(L_0 - 1)$$

$$|P\rangle$$

$$u_{\nu} a_{-1}^{\nu} \bar{a}_{-1}^{\nu} |P\rangle$$

$$L_n |P\rangle = 0 \quad n > 0$$

$$\langle P | L_n = 0 \quad n < 0$$

$$\phi^{\mu\nu} \rightarrow \phi^{\mu\nu} + \partial^\mu \psi^\nu + \partial^\nu \psi^\mu$$

$$\phi^{\mu\nu} \quad \square^2 \phi^{\mu\nu} = 0$$

$$L_0 |P\rangle = \frac{p^2}{2} |P\rangle$$

$$L_1 \epsilon_{\mu\nu} a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle = \epsilon_{\mu\nu} p^\mu \bar{a}_{-1}^\nu |P\rangle$$

$$L_{-1} (u_\mu \bar{a}_{-1}^\mu |P\rangle) = p_\nu u_\nu a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle$$

$$(L_0 - 1) (\dots)$$

$$\epsilon_{\mu\nu} p^\mu = 0$$

$$\boxed{p^2 = 0}$$

VULL

$$L_n |P\rangle = 0 \quad n > 0$$

$$\langle P | L_n = 0 \quad n < 0$$

$$\phi^{\mu\nu} \rightarrow \phi^{\mu\nu} + \partial^\mu \psi^\nu + \partial^\nu \psi^\mu$$

$$\begin{aligned} & a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle \\ & [a_{-1}^\mu \bar{a}_{-1}^\nu - \frac{1}{2} \eta^{\mu\nu} a_{-1}^\sigma \bar{a}_{-1}^\sigma] |P\rangle \\ & a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle \end{aligned}$$

$$\phi^{\mu\nu}$$

$$\square^2 \phi^{\mu\nu} = 0$$

$$\epsilon_{\mu\nu} a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle$$

$$L_1 \epsilon_{\mu\nu} a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle = \epsilon_{\mu\nu} p^\mu a_{-1}^\nu$$

$$\epsilon_{\mu\nu} p^\mu = 0 \quad \epsilon_{\mu\nu} p^\nu = 0$$

$$\square^2 = 0$$

$$\begin{aligned} & L_{-1} (u_\mu \bar{a}_{-1}^\mu |P\rangle) = \\ & (L_0 - 1) (\dots) \end{aligned}$$

$$\text{NULL } \epsilon_{\mu\nu} = p_\mu u_\nu + \bar{u}_\mu p_\nu$$

$$L_n |P\rangle = 0 \quad n > 0$$

$$\langle P | L_n = 0 \quad n < 0$$

$$\phi^{\mu\nu} \rightarrow \phi^{\mu\nu} + \partial^\mu U^\nu + \partial^\nu U^\mu$$

$$\begin{aligned} & a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle \\ & [a_{-1}^\mu \bar{a}_{-1}^\nu - \frac{1}{2} \eta^{\mu\nu} a_{-1}^\sigma \bar{a}_{-1}^\sigma] |P\rangle \\ & a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle \end{aligned}$$

$$\phi^{\mu\nu}$$

$$\square^2 \phi^{\mu\nu} = 0$$

$$\epsilon_{\mu\nu} a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle$$

$$L_1 \epsilon_{\mu\nu} a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle = \epsilon_{\mu\nu} p^\mu \bar{a}_{-1}^\nu |P\rangle$$

$$\epsilon_{\mu\nu} p^\mu = 0 \quad \epsilon_{\mu\nu} p^\nu = 0$$

$$\square^2 = 0$$

$$L_{-1} (u_\nu \bar{a}_{-1}^\nu |P\rangle) = p_\mu u_\nu a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle$$

$$(L_0 - 1) (\dots)$$

$$\text{NULL } \epsilon_{\mu\nu} = p_\mu u_\nu + \bar{u}_\mu p_\nu$$

$$L_n |P\rangle = 0 \quad n > 0$$

$$\langle P | L_n = 0 \quad n < 0$$

$$\phi^{\mu\nu} \rightarrow \phi^{\mu\nu} + \partial^\mu \psi^\nu + \partial^\nu \psi^\mu$$

$$\begin{aligned} & a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle \\ & [a_{-1}^\mu \bar{a}_{-1}^\nu - \frac{1}{2} \eta^{\mu\nu} a_{-1}^\sigma \bar{a}_{-1}^\sigma] |P\rangle \\ & a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle \end{aligned}$$

$$\phi^{\mu\nu}$$

$$\square^2 \phi^{\mu\nu} = 0$$

$$\epsilon_{\mu\nu} a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle$$

$$L_1 \epsilon_{\mu\nu} a_{-1}^\mu \bar{a}_{-1}^\nu |P\rangle = \epsilon_{\mu\nu} p^\mu \bar{a}_{-1}^\nu |P\rangle$$

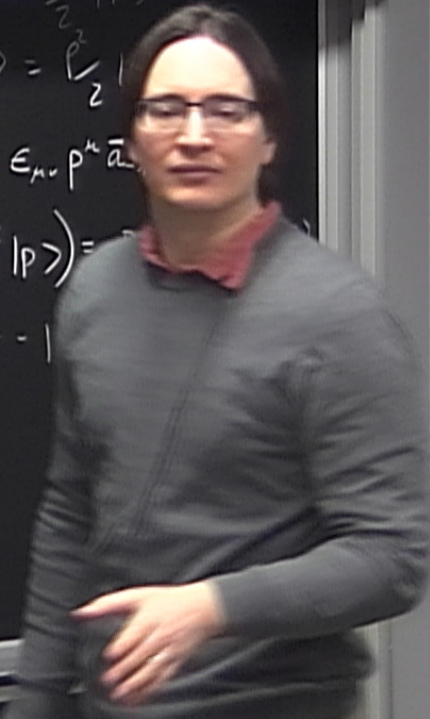
$$\epsilon_{\mu\nu} p^\mu = 0 \quad \epsilon_{\mu\nu} p^\nu = 0$$

$$\square^2 = 0$$

$$L_{-1} (u_\mu \bar{a}_{-1}^\mu |P\rangle) = \dots$$

$$(L_0 - 1) (\dots)$$

$$\text{NULL } \epsilon_{\mu\nu} = p_\mu u_\nu + \bar{u}_\mu p_\nu$$



a_n^μ, \bar{a}_n^μ

$$[a_n^\mu, a_{-n}^\nu] = m \eta^{\mu\nu} \delta_{n+m,0}$$

$$\langle P | a_{-1}^\nu a_{-1}^\mu | P' \rangle = \eta^{\mu\nu} \delta(P-P')$$

$\bar{a}_{-1}^{\mu'} \bar{a}_{-1}^{\nu'} | P \rangle$

$\bar{a}_{-2}^{\mu'} | P \rangle$

$$a_n^\mu, \bar{a}_m^\mu$$

$$[a_n^\mu, a_{-m}^\nu] = \delta_{n+m,0} \eta^{\mu\nu}$$

$$\langle P | a_{-1}^\nu a_{-1}^\mu | P' \rangle = \eta^{\mu\nu} \delta(P-P')$$

$$a_{-1}^\mu a_{-1}^\nu \bar{a}$$

$$a_{-1}^\mu a_{-1}^\nu \bar{a}$$

$$a_{-2}^\mu \bar{a}_{-1}^\nu$$

$$a_{-2}^\mu a_{-1}^\nu$$

CAUTION

BE CAREFUL NOT TO TOUCH THE BOARD SURFACE

DO NOT TOUCH THE BOARD SURFACE

PLEASE DO NOT TOUCH THE BOARD SURFACE

CAUTION

$$a_n^\mu, \bar{a}_n^\mu$$

$$[a_n^\mu, a_{-n}^\nu] = m \eta^{\mu\nu} \delta_{n+m,0}$$

$$\langle P | a_{-1}^\nu a_{-1}^\mu | P \rangle \delta(P-P')$$

$$P^2 = -2$$

$$L_1$$

$$a_{-1}^\mu a_{-1}^\nu \bar{a}_{-1}^{\mu'} \bar{a}_{-1}^{\nu'} |P\rangle$$

$$a_{-1}^\mu a_{-1}^\nu \bar{a}_{-2}^{\mu'} |P\rangle$$

$$a_{-2}^\mu \bar{a}_{-1}^{\mu'} \bar{a}_{-1}^{\nu'} |P\rangle$$

$$a_{-2}^\mu a_{-2}^{\mu'} |P\rangle$$

$$i\partial_3 X = p + \sum_{n \neq 0} a_n e^{-ns} \quad -i\partial_5 X = -p + \sum_{n \neq 0} a_n e^{-ns}$$

$$a_n^\mu, \bar{a}_n^\mu$$

$$[a_n^\mu, a_{-n}^\nu] = m \eta^{\mu\nu} \delta_{n+m,0}$$

$$\langle p | a_{-1}^\nu a_{-1}^\mu | p \rangle = (p-p')$$

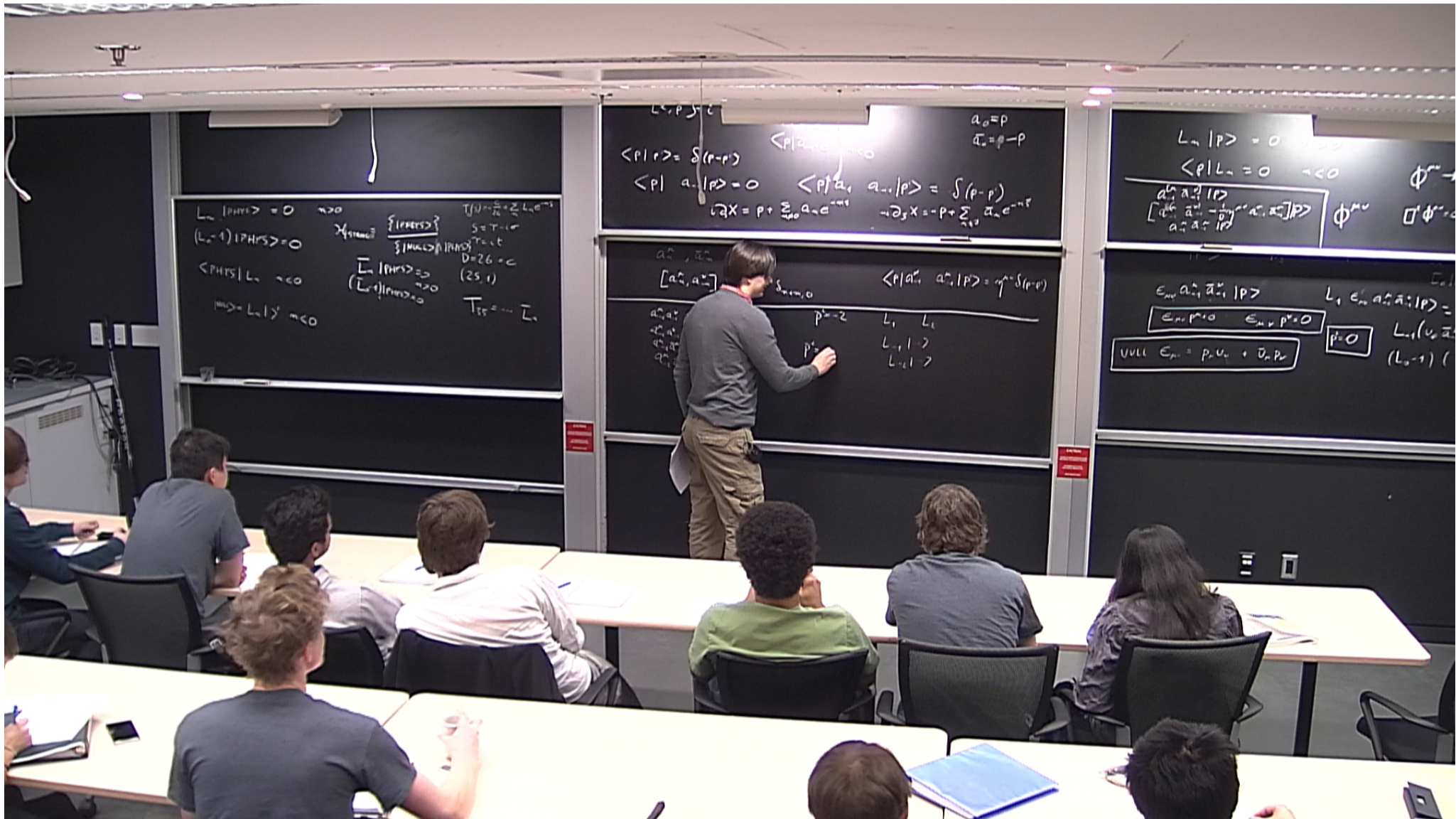
$$p^z = -2$$

$L_1 \quad L_2$
 L_-

- $a_{-1}^\mu a_{-1}^\nu \bar{a}_{-1}^{\mu'} \bar{a}_{-1}^{\nu'} |p\rangle$
- $a_{-1}^\mu a_{-1}^\nu \bar{a}_{-2}^{\mu'} |p\rangle$
- $a_{-2}^\mu \bar{a}_{-1}^{\mu'} \bar{a}_{-1}^{\nu'} |p\rangle$
- $a_{-2}^\mu a_{-2}^{\mu'} |p\rangle$

CAUTION
DO NOT TOUCH THE BOARD OR BOARD ERASER AT THE END OF THE HOUR
DO NOT TOUCH THE BOARD OR BOARD ERASER AT THE END OF THE HOUR
PLEASE RESPECT THE BOARD

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$$L_n |p\rangle = 0 \quad n > 0$$

$$(L_{-1}) |p\rangle = 0$$

$$\langle p | L_n |p\rangle = 0$$

$$\langle p | L_{-1} |p\rangle = 0$$

$$L_{-1} |p\rangle = 0$$

$$L_{-1} |p\rangle = 0$$

$$L_n |p\rangle = 0$$

$$\langle p | L_n |p\rangle = 0$$

$$\langle p | L_{-1} |p\rangle = 0$$

$$L_{-1} |p\rangle = 0$$

$$L_{-1} |p\rangle = 0$$

$$[a_n^{\mu}, a_m^{\nu}] = i \eta^{\mu\nu} \delta_{n+m,0}$$

$$L_n = \frac{1}{2} \sum_{k=-\infty}^{\infty} a_{-k}^{\mu} a_k^{\mu}$$

$$L_{-1} |p\rangle = 0$$

$$L_{-1} |p\rangle = 0$$

$$L_{-1} |p\rangle = 0$$

$$L_n |p\rangle = 0$$

$$\langle p | L_n |p\rangle = 0$$

$$\langle p | L_{-1} |p\rangle = 0$$

$$L_{-1} |p\rangle = 0$$

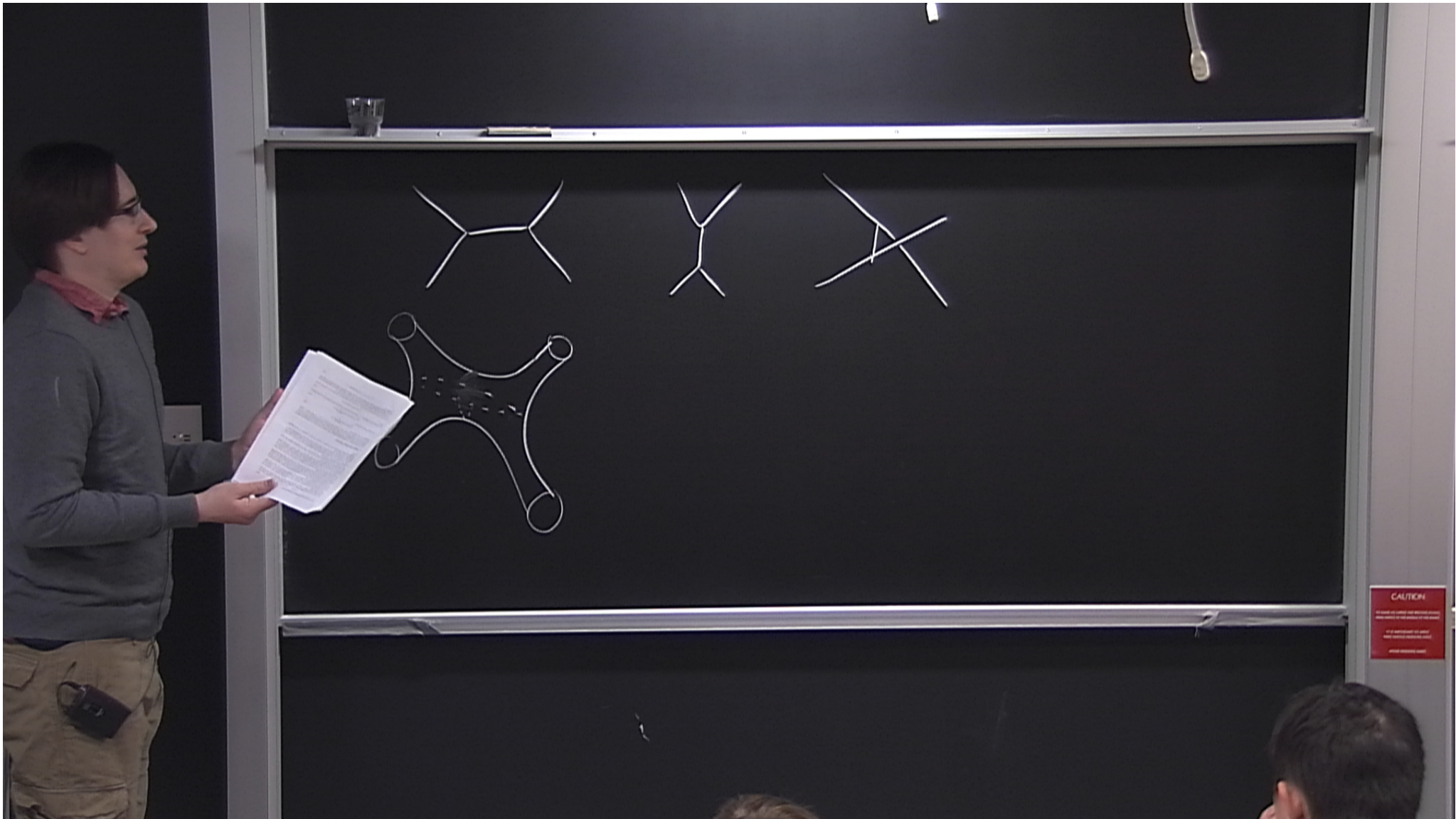
$$L_{-1} |p\rangle = 0$$

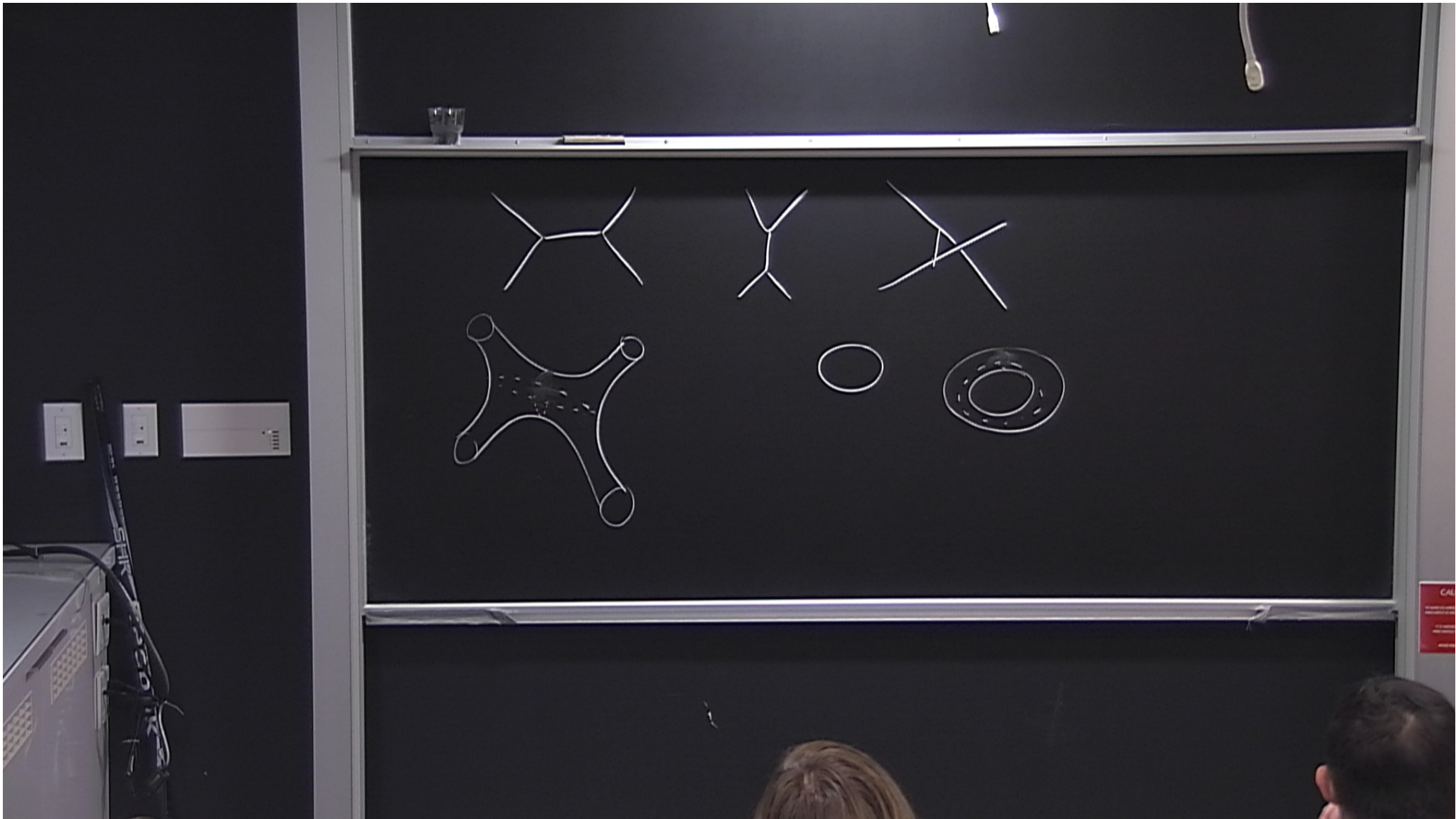
$$L_n = \frac{1}{2} \sum_{k=-\infty}^{\infty} a_{-k}^{\mu} a_k^{\mu}$$

$$L_{-1} |p\rangle = 0$$

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$$L_{-1} |p\rangle = 0$$





$$z \rightarrow z + f(z)$$

$$f(z) \frac{\partial}{\partial z}$$

$$\left\{ e^{ms} \frac{\partial}{\partial s}, e^{ms} \frac{\partial}{\partial \bar{s}} \right\}$$



$$a_n^\mu, \bar{a}_n^\mu$$

$$[a_n^\mu, a_{-n}^\nu] = m \eta^{\mu\nu}$$

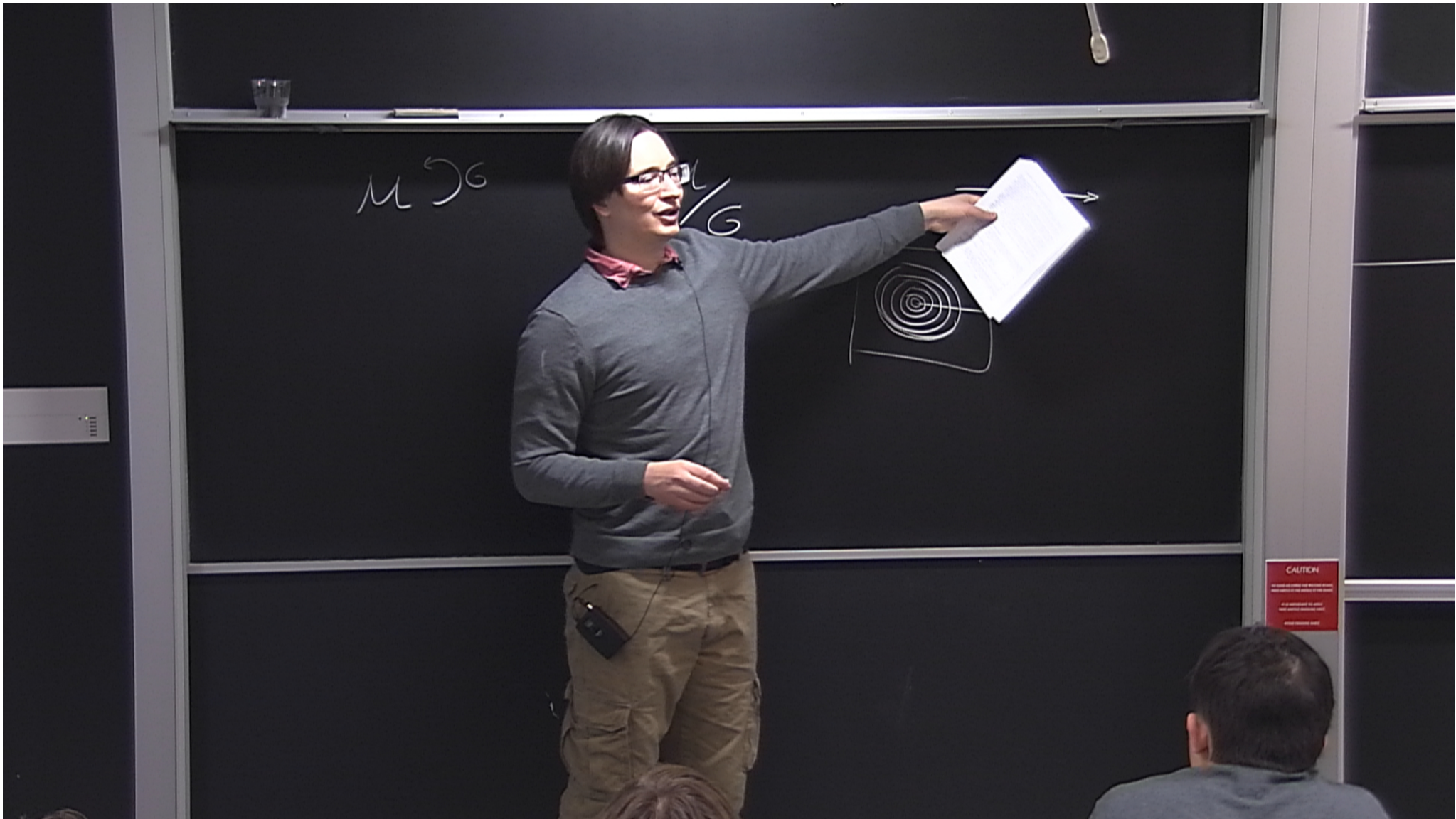
$$a_{-1}^\mu a_{-1}^\nu \bar{a}_{-1}^{\mu'} \bar{a}_{-1}^{\nu'} |P\rangle$$

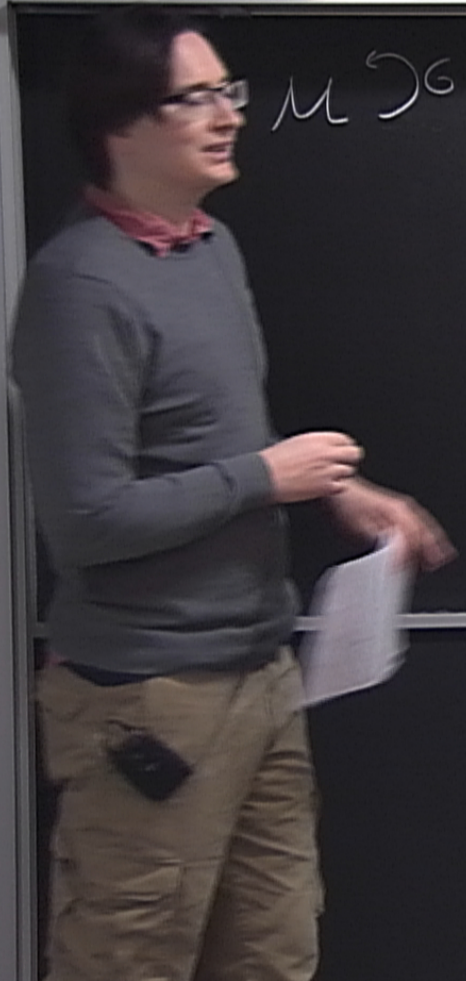
$$a_{-1}^\mu a_{-1}^\nu \bar{a}_{-2}^{\mu'} |P\rangle$$

$$a_{-2}^\mu \bar{a}_{-1}^{\mu'} \bar{a}_{-1}^{\nu'} |P\rangle$$

$$a_{-2}^\mu \bar{a}_{-2}^{\mu'} |P\rangle$$

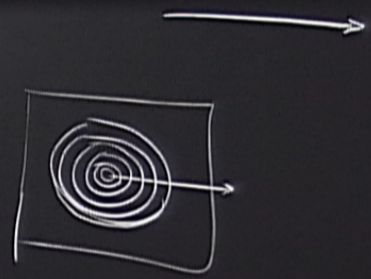
CAUTION





M/G

M/G
 $\int F(z) z dz d\varphi$



CAUTION
Do not touch the blackboard surface
as it is very hot. Please do not touch the blackboard surface.

