Title: Quantum Thermodynamics

Date: Jul 20, 2016 05:00 PM

URL: http://pirsa.org/16070022

Abstract:

What is Quantum thermodynamics?

- 3 laws
- Resource Theory

Many second laws

Embezzling Work

Q Fluctuation relations

Third law

τ_2 τ_3

$\longrightarrow \tau$ τ_3

1st law $dE = dQ - dW$ conservation of energy

2nd law heat can never pass from a cold system to a warm one without some other "change" occuring elsewhere

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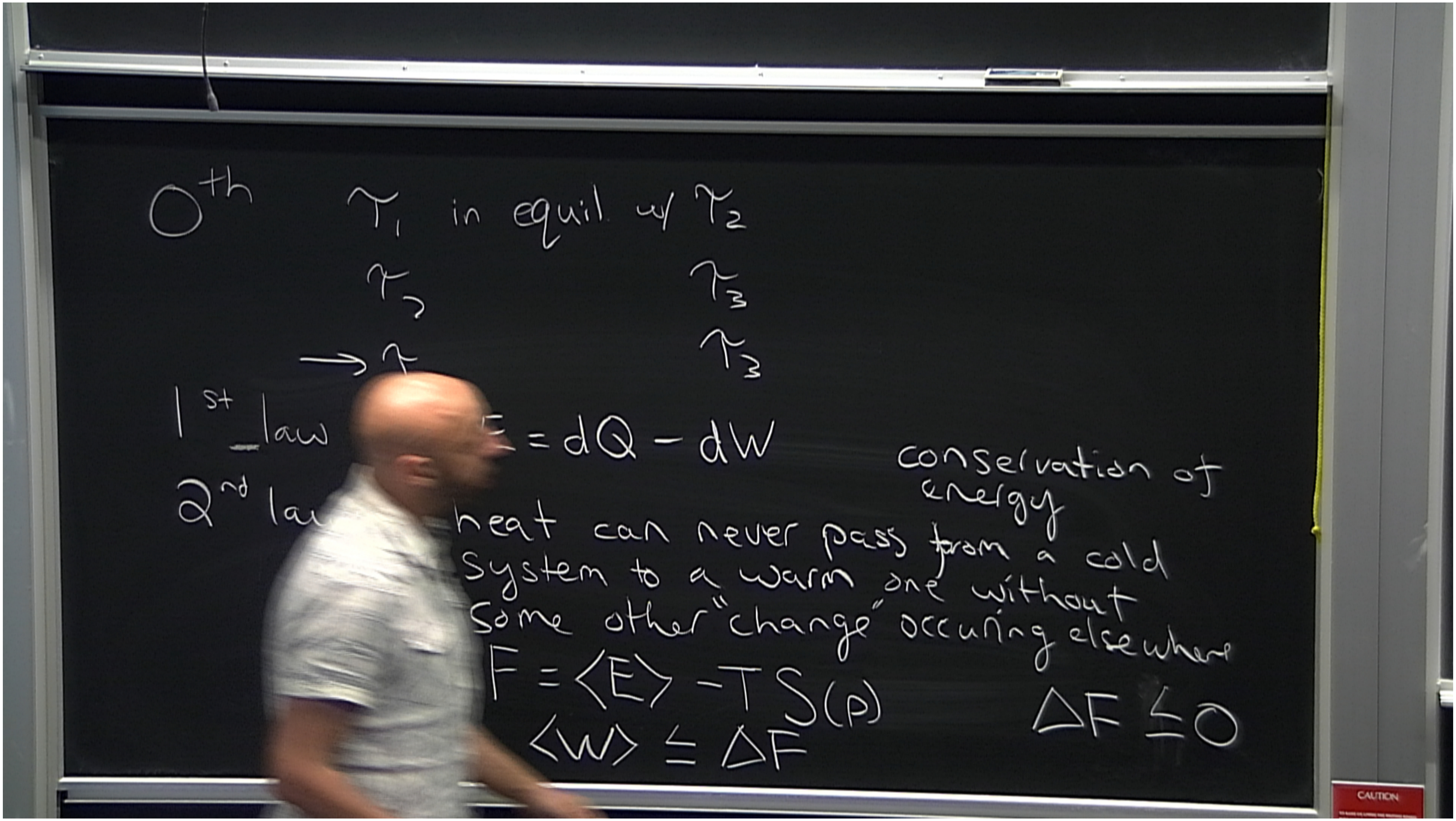
2^{nd} law heat can never pass from a cold system to a warm one without some other "change" occuring elsewhere

$$F = \langle E \rangle - TS(\rho) \qquad \Delta F \leq 0$$

$$\langle W \rangle \leq \Delta F$$


0th τ1 in equil w/ τ2
τ2 τ3
→ τ τ3
1st law E = dQ − dW
conservation of energy
2nd law heat can never pass from a cold
system to a warm one without
some other "change" occuring elsewhere
F = ⟨E⟩ − TS(ρ)
ΔF ≤ 0
⟨W⟩ ≤ ΔF

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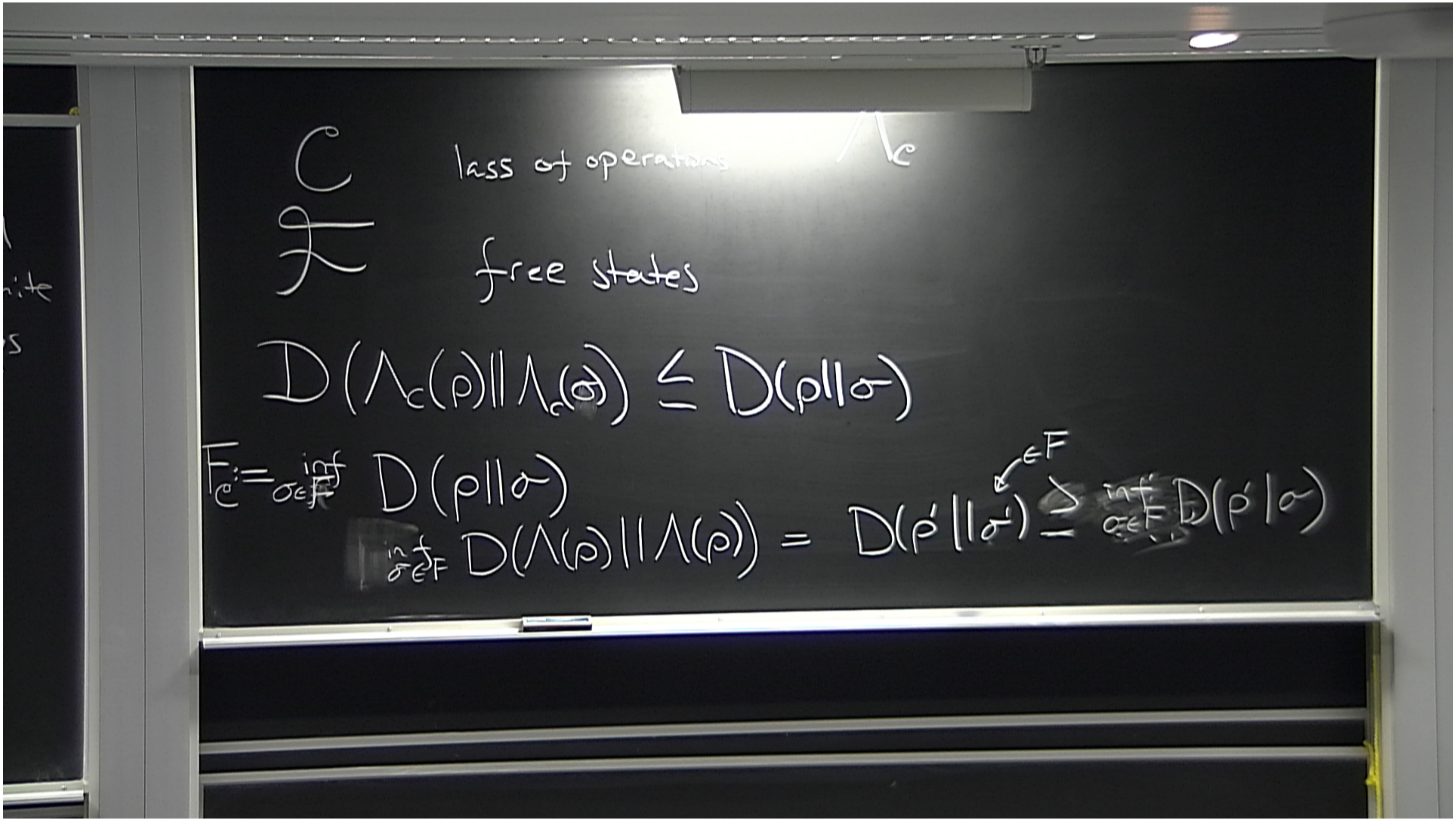
3rd law: it's impossible to cool to $T \to 0$ in a finite number of steps



$\mathcal{C}$ lass of operations Λ_c
$\mathcal{F}$ free states
$D(\Lambda_c(\rho)\|\Lambda_c(\sigma)) \leq D(\rho\|\sigma)$
$F_{\mathcal{C}} := \inf_{\sigma\in F} D(\rho\|\sigma)$
$\in F$
$\inf_{\sigma\in F} D(\Lambda(\rho)\|\Lambda(\rho)) = D(\rho'\|\sigma') \geq \inf_{\sigma\in F} D(\rho'|\sigma)$

(Catalytic) Thermal Operations (C) T.O.

- ρ_S, H_S quasi-classical $[\rho_S, H_S] = 0$
- Free γ_β, H_R
- W, H_W $[\Delta, H_W] = -i$ $H_W = \sum \omega_n |n\rangle\langle n|$
- $[U, H_S + H_R + H_W] = 0$

- $[U, \Delta] = 0$
- allow borrowing σ_c, H_c as long as its returned in the "same" state

0th law $\tau_\beta = e^{-\beta H_R}/Z, H_R$ or we can draw an arbitrarily large amount of work (complete passivity)

$$\Lambda_{cyclic}(\tau_\beta) = \tau_\beta$$

$$TD_1(\rho \| \tau_\beta) = T[\mathrm{tr}\rho\log\rho - \mathrm{tr}\rho\log\tau_\beta]$$
$$= \langle E \rangle - TS + \log Z$$

take $H_S = H_R = 0$

Λ is a doubly stochastic map

$\rho \to \sigma$ iff $\rho \succ \sigma$

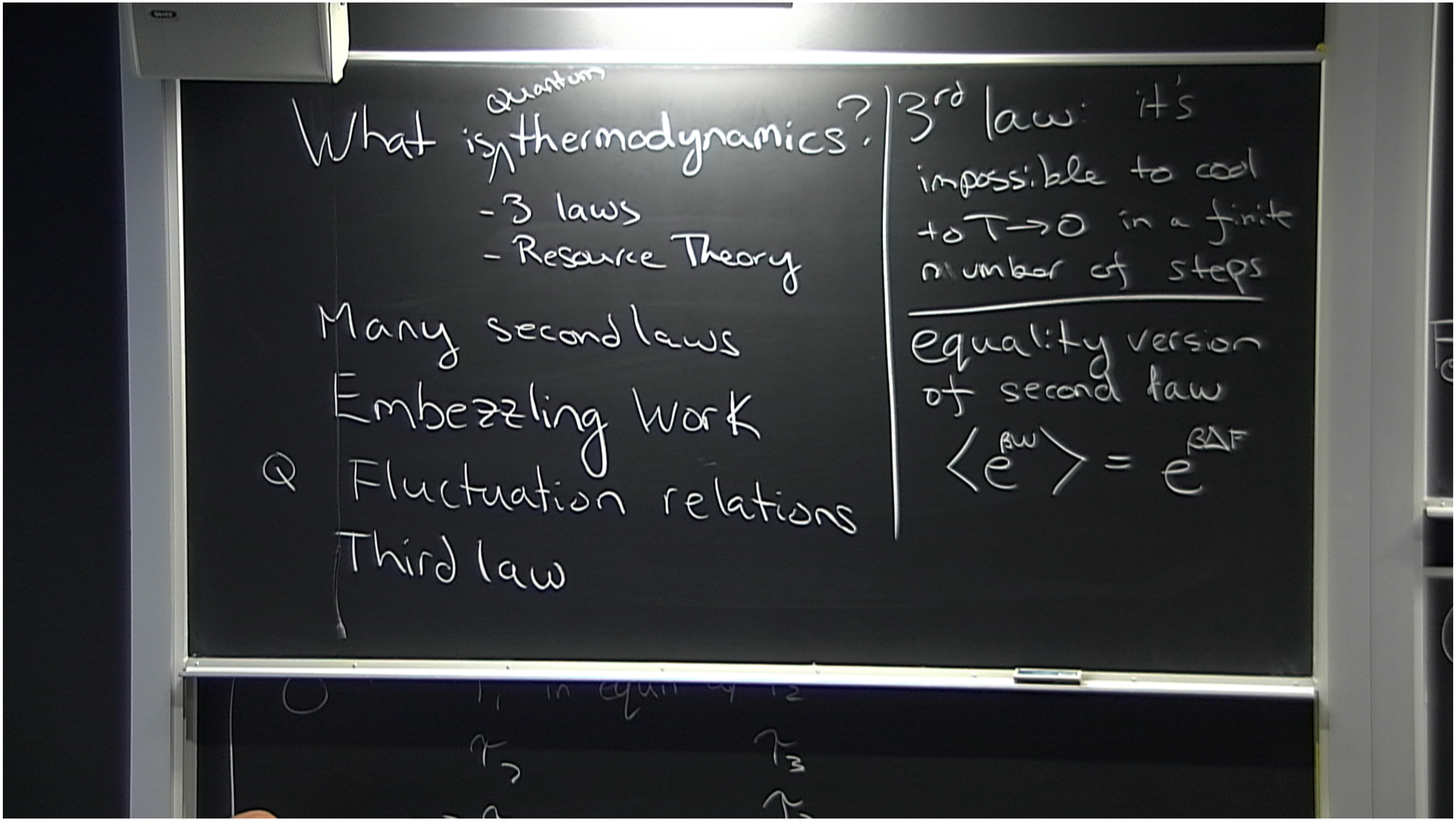
ts returned
state

$$D_\alpha(\rho\|\sigma) = \frac{1}{1-\alpha}\log \operatorname{tr} \rho^{\alpha}\sigma^{1-\alpha}$$

$D_\alpha(\rho\|\gamma_\beta)$ is a monotone under (C)TO

$\rho \xrightarrow{CTO} \sigma$ iff $D_\alpha(\rho\|\gamma_\beta) \geq D_\alpha(\sigma\|\gamma_\beta)$ $\alpha \geq 0$

in thermodynamic limit $D_\alpha \simeq D_1$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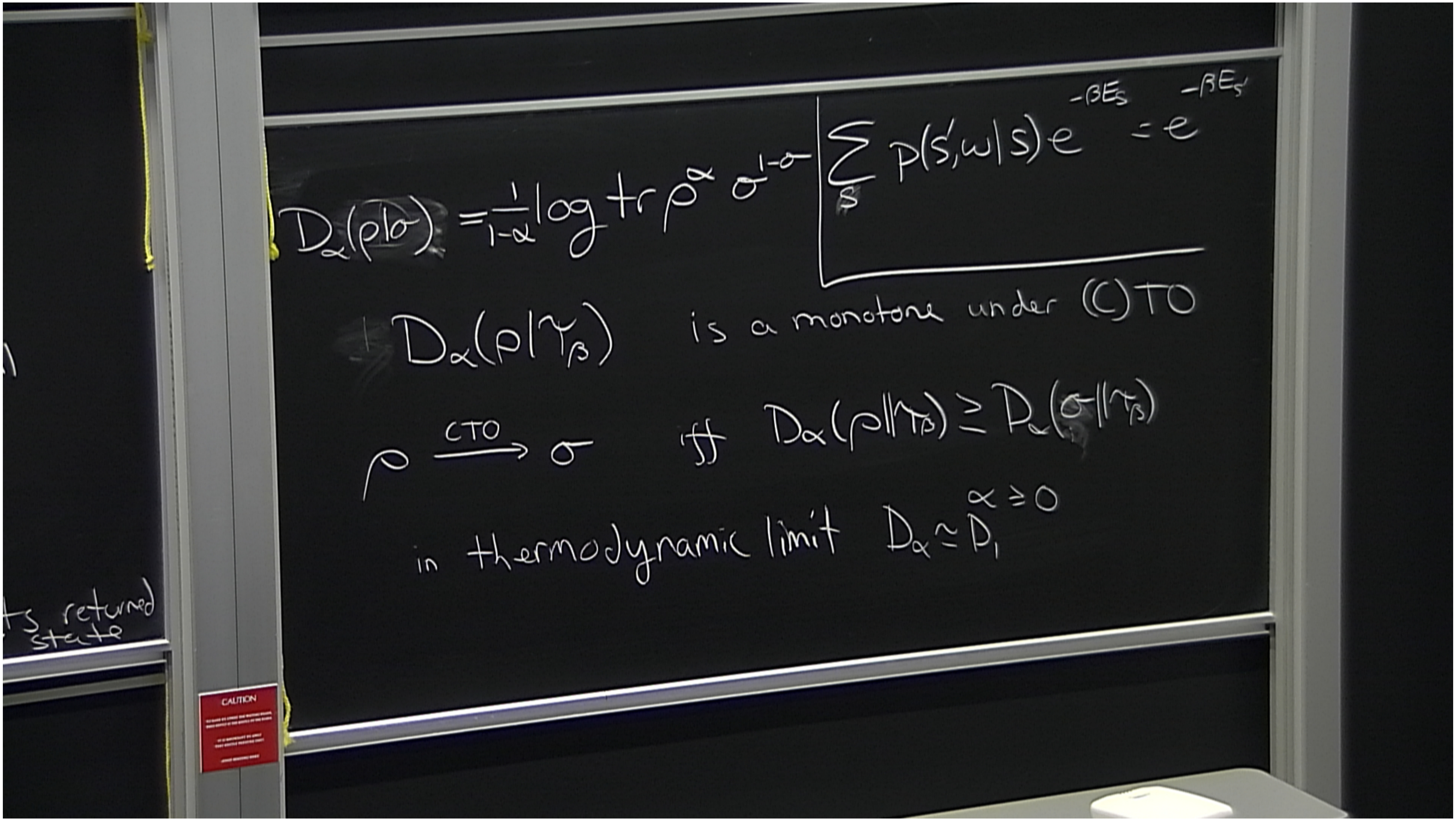
3rd law: it's impossible to cool to T→0 in a finite number of steps
equality version of second law
⟨e^{βW}⟩ = e^{βΔF}


$D_\alpha(\rho\|\sigma) = \frac{1}{1-\alpha}\log \mathrm{tr}\,\rho^\alpha\sigma^{1-\alpha}$
$\sum_s p(s',\omega|s)e^{-\beta E_s} = e^{-\beta E_{s'}}$
$D_\alpha(\rho\|\gamma_\beta)$ is a monotone under (C)TO
$\rho \xrightarrow{CTO} \sigma$ iff $D_\alpha(\rho\|\gamma_\beta) \geq D_\alpha(\sigma\|\gamma_\beta)$
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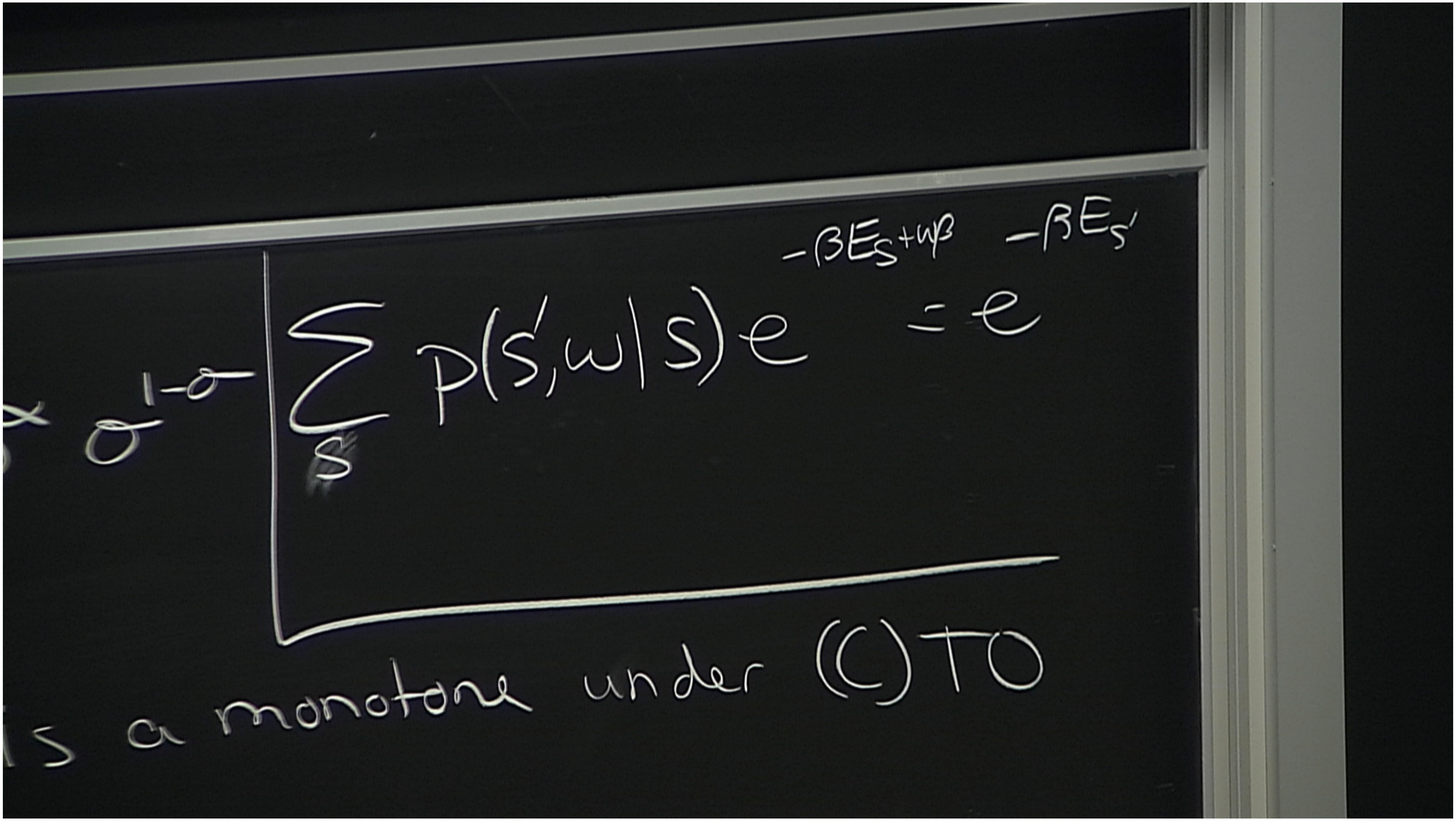
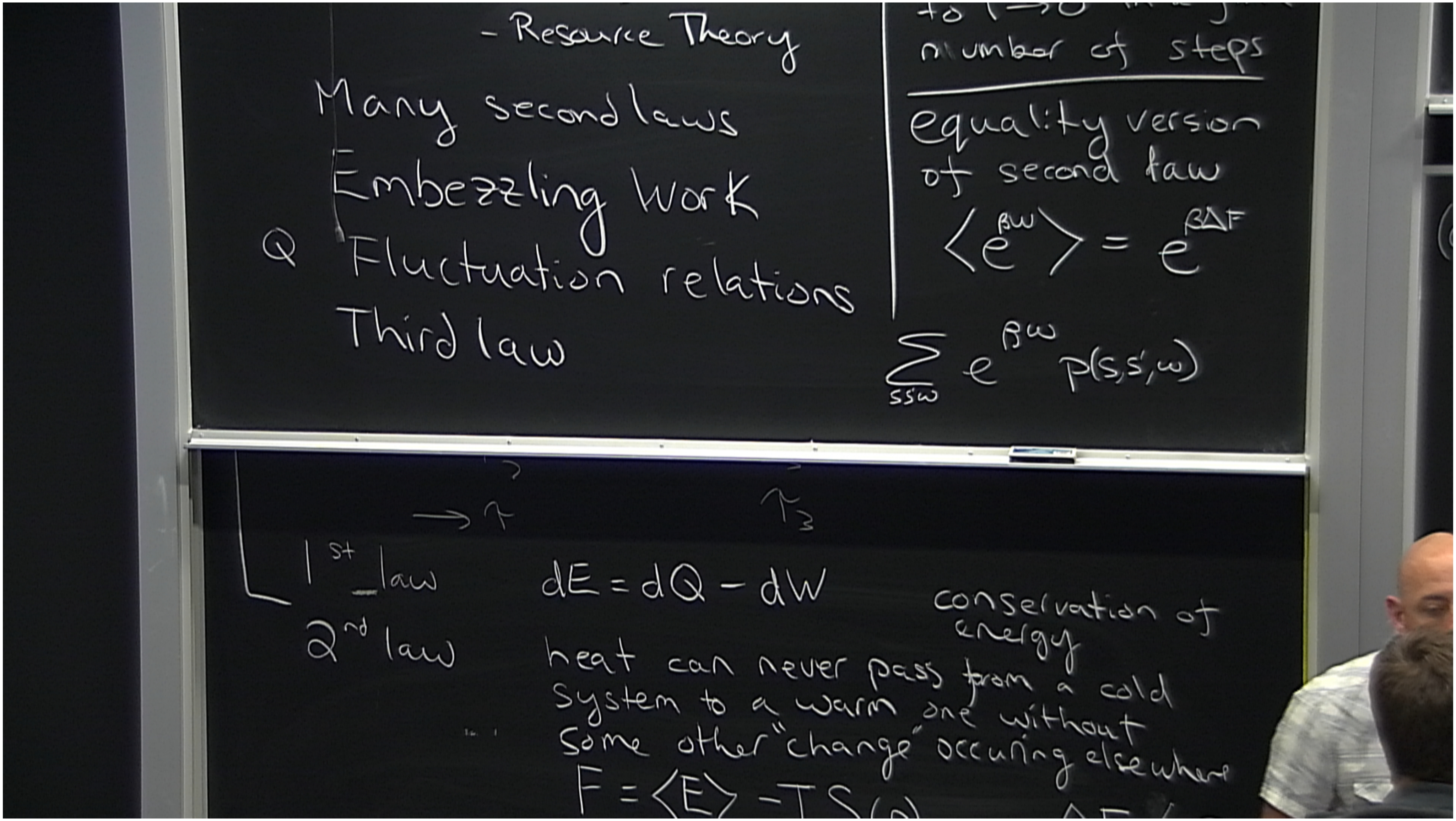
CAUTION


$\sigma^{1-\sigma}$
$\sum_{s} p(s', w|s)\, e^{-\beta E_s + w\beta} = e^{-\beta E_{s'}}$
is a monotone under (C)TO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Many second laws
Embezzling Work
Q Fluctuation relations
Third law
number of steps
equality version
of second law
$\langle e^{\beta W} \rangle = e^{\beta \Delta F}$
$\sum_{ss'w} e^{\beta w} p(s,s',w)$
T_3
1^{st} law
$dE = dQ - dW$
conservation of energy
2^{nd} law
heat can never pass from a cold system to a warm one without some other "change" occuring elsewhere