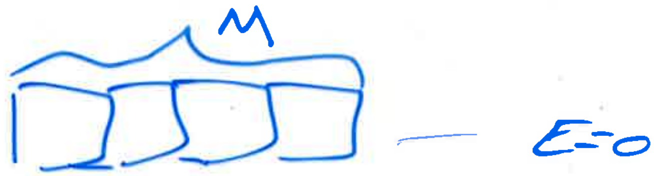
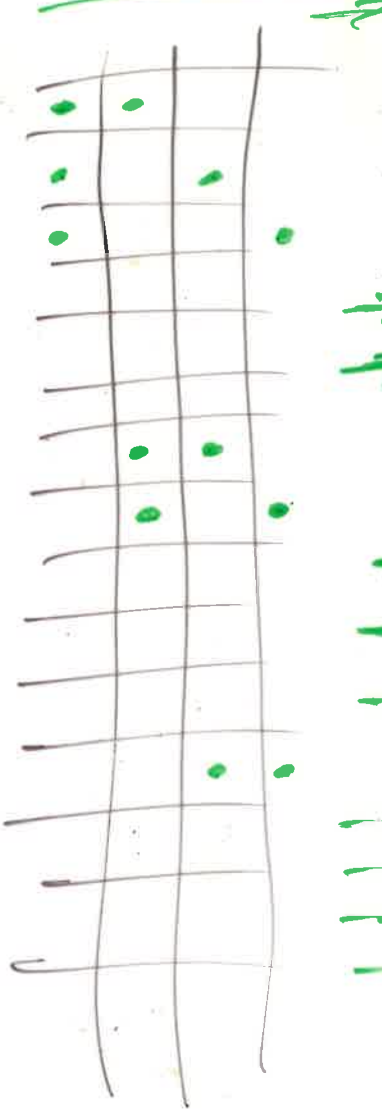
Quantum Statistics

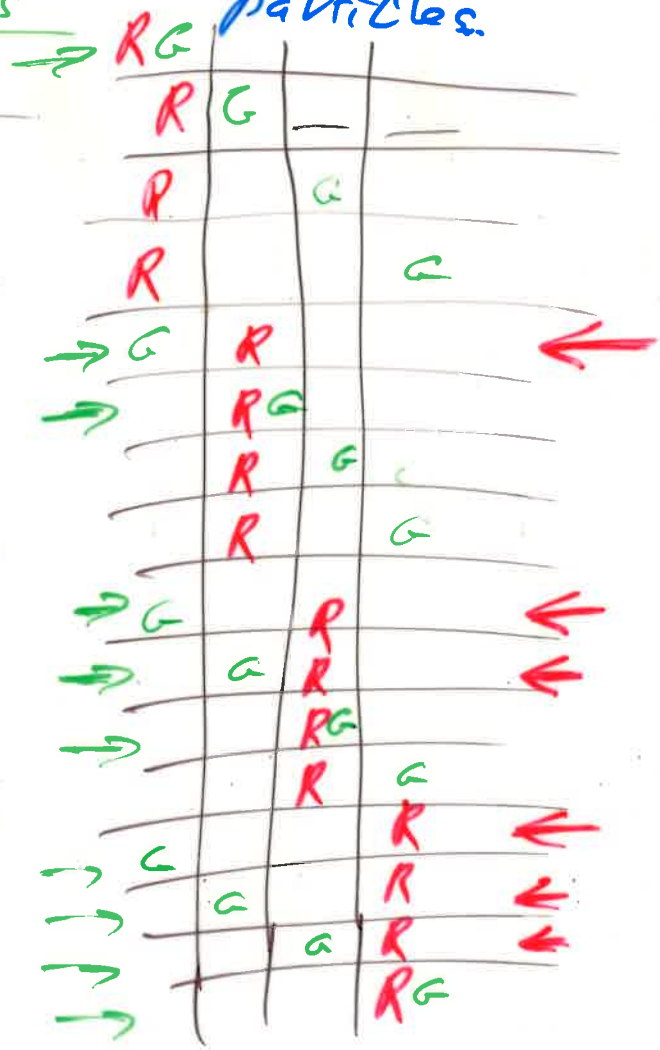


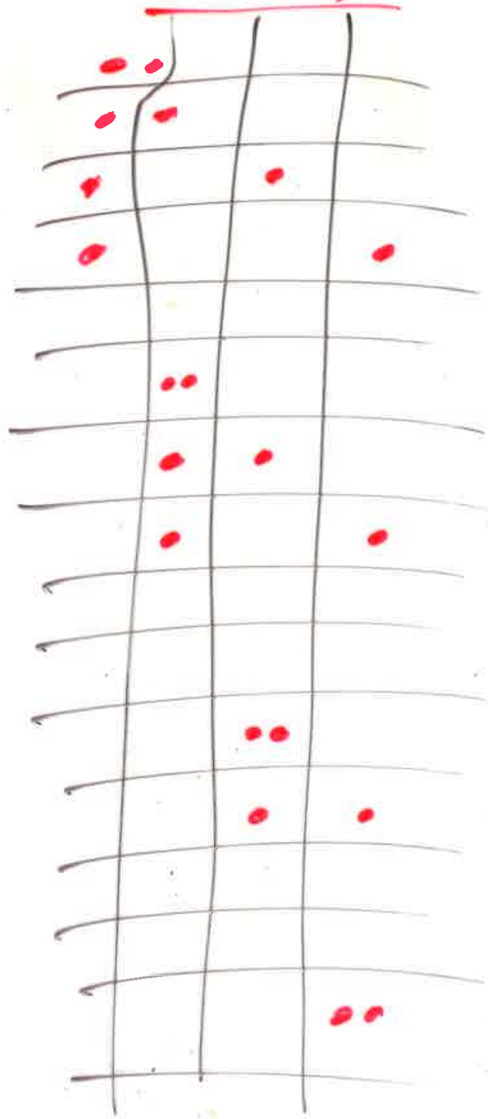
(Indistinguishable) Fermions

2 Classical Distinguishable particles

(Indistinguishable) Bosons







6

$16 = M^2$

10

Classical particle Indistinguishable

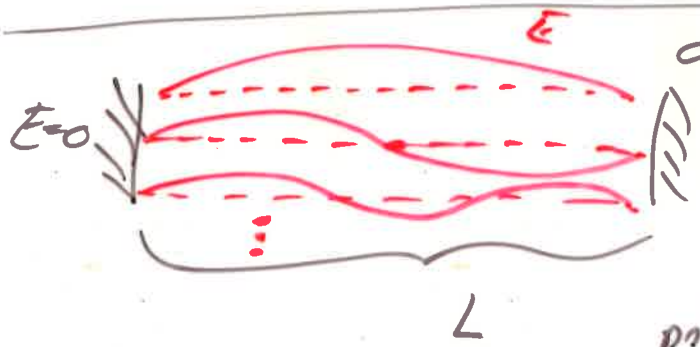
$$\frac{M^2}{2!} = 8$$

3 problems with 19^{th} century physics

① Black body radiation + the UV catastrophe (Rayleigh-Jeans catastrophe)

② C_v for a diatomic gas

③ Specific heat of solids – especially metals



one-dimensional "box"

$\lambda = \frac{2L}{n}$ $\quad n = 1, 2, 3 \ldots$

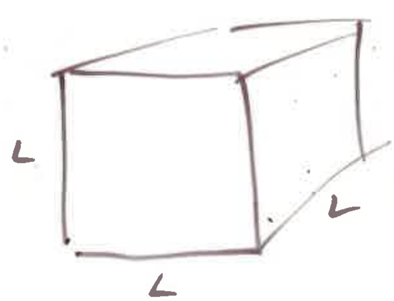
$\nu = \frac{c}{\lambda} = \frac{cn}{2L}$

$n = \frac{2L}{c}\nu$

polarizations

$$N(\nu)\,d\nu = 2\,\frac{2L}{c}\,d\nu$$

Three dimensions

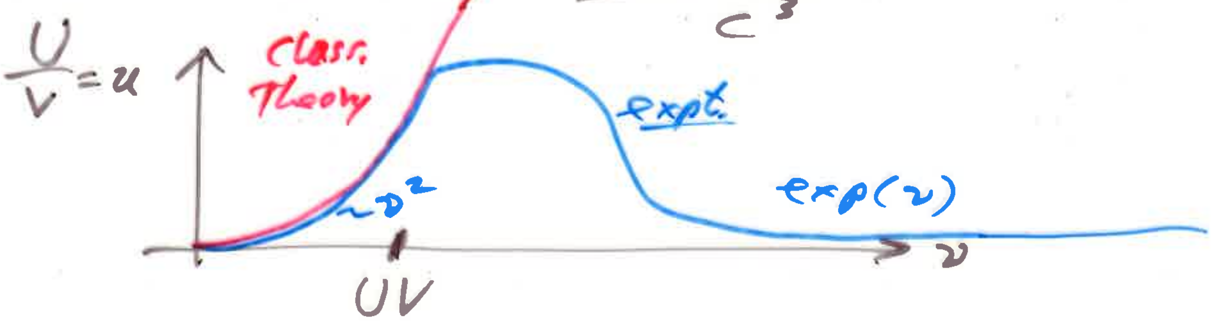


$$N(\nu)\,d\nu = \frac{2L^3}{c^3}\,4\pi\nu^2\,d\nu$$

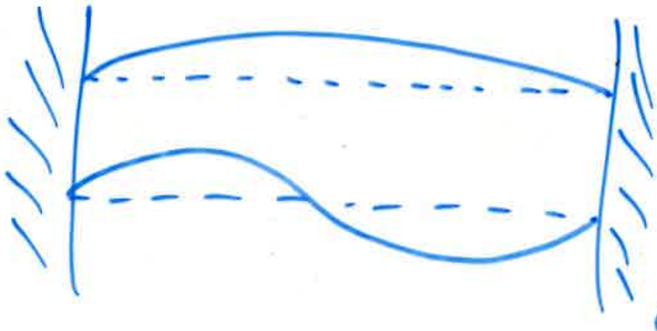
Classically: equipartition theorem

$\Longrightarrow k_BT$ per mode

$$U(\nu)d\nu = V\,\frac{8\pi k_BT\,\nu^2\,d\nu}{c^3}$$



Classically for a string



fundamental $\lambda = 2L$, $\nu = \frac{c}{\lambda} = \frac{c}{2L}$

1^{st} overtone (2nd harmonic) $\lambda = L$, $\nu = \frac{c}{\lambda} = \frac{c}{L}$

λ, ν <u>are</u> quantized

Energy E is not quantized.

Quantum Mechanics

$$E_n = (n+\tfrac{1}{2})\hbar\omega = (n+\tfrac{1}{2})h\nu \qquad n = 0, 1, 2 \ldots$$

$E_0 = \frac{1}{2}h\nu$ ground state energy.

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$R_{\mu\nu} - \tfrac{1}{2}R g_{\mu\nu} + \Lambda g_{\mu\nu}$$