How lectures will work

Course webpage

- Zoom lectures
- Recorded & posted to watch again
- Notes & Readings available ahead
- PDF of "chalkboard" available after

5 minute "breather" break ~ ½ way through

Feel free to interrupt.

If you can — camera on. (Feeling of isolation)

In English (why? ....)

How the course will work

- webpage - Schedule, Readings, homeworks/sol'ns.
- Readings: 2 books - QFT = Peskin & Schroeder
  = Srednicki
- Lecture notes (maybe not super-easy)
- Added readings
- Lectures & their recordings

Every component is important!

65% 1.7
70% 1.3
75% 1.0

- Homework

100% homework grade, 60% to pass.

Option - oral exam. You don't want to do that!

$$g_{\mu\nu} = \eta_{\mu\nu} = \begin{array}{c} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & +1 & 0 & 0 \\ 0 & 0 & +1 & 0 \\ 0 & 0 & 0 & +1 \end{bmatrix} \end{array} \begin{array}{c} t \\ x \\ y \\ z \end{array} \quad \text{or} \quad \begin{bmatrix} +1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

Warning - Quantum Field Theory is hard

- Lots of time
- Do homework
- Ask questions! Interrupt lecture....

QFT is important.

Fundamental language of

- All part. physics
- "most" nuclear physics
- Much Cond. Matt physics
- Predictive, tested
- Intuition into other fields (GR)

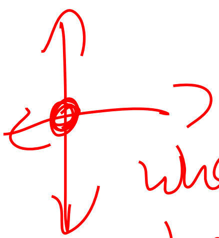
What Is Quantum Field Theory??

Classical vs Quantum

point part. vs. field

Class Point part: part is at location $\vec{r}$ at time t

→ Descrip. of system $\vec{r}(t)$ — time hist. of system.



where is the dot?

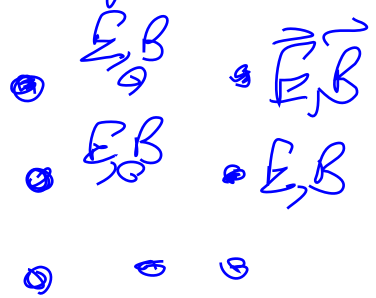
$$L = L(\vec{r}, \dot{\vec{r}}) = \frac{m}{2}\dot{r}^2 + V(\vec{r})$$

$$S = \int dt\, L \quad \text{dep. on history} \qquad \frac{\delta S}{\delta r(t)} = 0 \Rightarrow \text{dyn.}$$

Class field - $\vec{r}(t)$ 3 #s for descr.

1 or 3 or 6 .. #'s at each point in space

$\vec{E}, \vec{B}(x)$



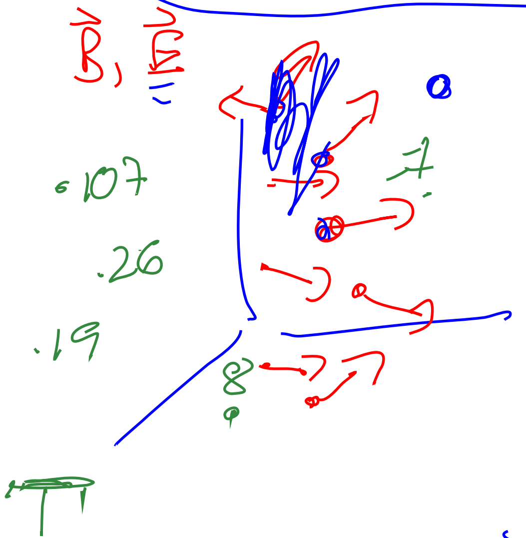
what happens at each pt. in space??

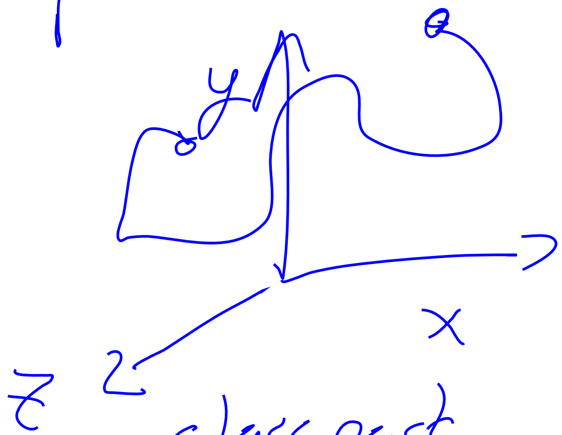
Class Field Theory

$$L(\vec{E}, \vec{B}(x,t)) = \int d^3x \left[\frac{B^2}{2} - \frac{E^2}{2}\right]$$

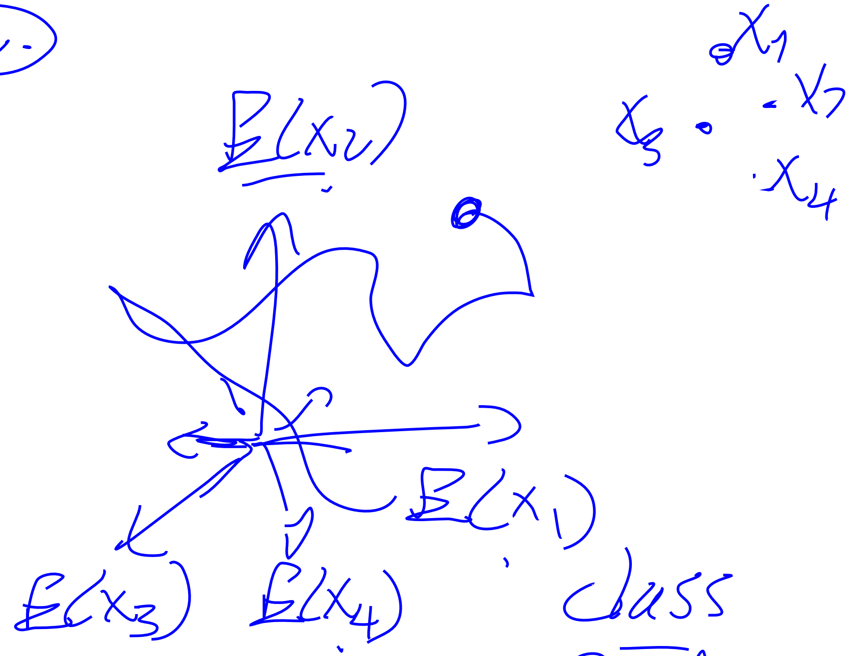
Every E-value (E at each pt.) is relevant.

∞ # of degrees of freedom.



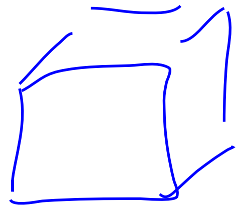


class part.



class field

Continuity – $\vec{E}$ with countable # of "values"



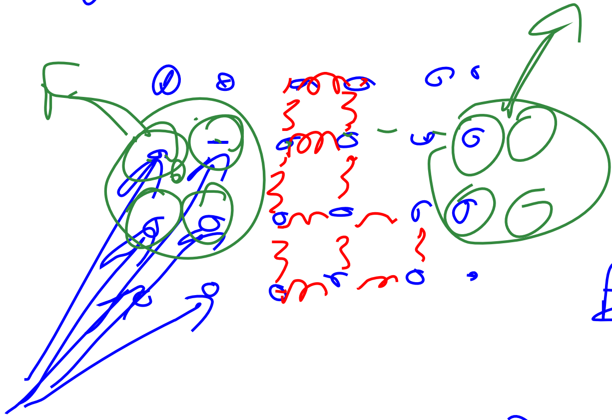
Fourier series

$$\vec{E}(x) = \sum_{\vec{p}} e^{i\vec{p}\cdot\vec{x}} \vec{E}_p$$

$$p = \frac{2\pi}{L}(\vec{n})$$

Field thy is the limit of other things when DOF get "very close together"

Crystalline solid



fine but finite grid of indiv. particles

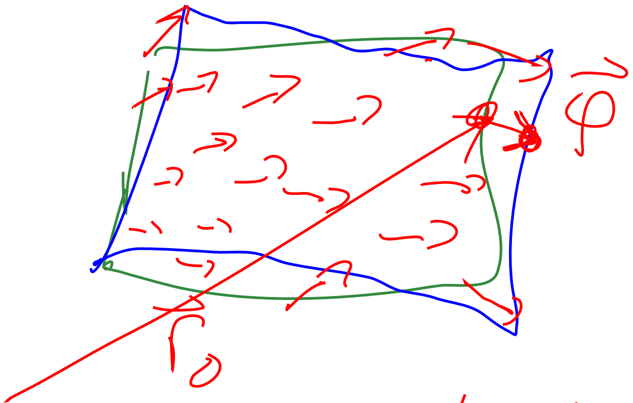
Each atom: 3 DOF x, y, z

$$L(\underbrace{\vec r_1, \vec r_2, \ldots}_{\text{finite but huge: } 10^{27\pm 3}}) = \frac{m}{2}\left(\dot{\vec r}_1^{\,2} + \dot{\vec r}_2^{\,2} + \ldots\right) + V(\vec r_1, \vec r_2, \vec r_3, \ldots)$$

finite but huge: $\boxed{10^{27\pm 3}}$

$$\vec r_i \longrightarrow \vec r_i - \vec r_{i0} \equiv \vec\varphi(\vec r_0)$$

$\vec r_{i0}$: avg or un-excited loc.



If you look on scales $\Delta x \gg$ "a" inter-atom spacing, $\vec\varphi(\vec r)$ looks like a continuous field

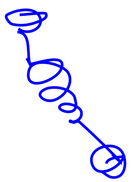
What is L?

$$L(\vec{\varphi}, \dot{\vec{\varphi}}; \vec{\nabla}\vec{\varphi}) = T_{kin} - V_{pot}.$$

$$T = \sum_{atoms} \frac{m}{2}\left((\partial_t \varphi_x)^2 + (\partial_t \varphi_y)^2 + (\partial_t \varphi_z)^2\right)$$

$i = x, y, z$ or $1, 2, 3$

$$\simeq \int d^3x \, \frac{\rho}{2} \, \partial_t \varphi_i \, \partial_t \varphi_i \qquad \sum_i \text{ implied.}$$



$$\sum_{r_1, r_2} \frac{C_{ijlm}}{2} \left(\varphi_i(r_1) - \varphi_j(r_1)\right)\left(\varphi_l(r_2) - \varphi_m(r_2)\right)$$

Vary smoothly, int's are short-range

$$\varphi_i(r_1) - \varphi_i(r_2) \simeq (r_1 - r_2)_j \, \partial_j \varphi_i + \frac{\delta r \, \delta r}{2} \partial\partial\varphi + \dots$$

$$V \to \int d^3x \, K_{ijlm} \, \partial_i \varphi_j \, \partial_l \varphi_m + K_{ijlmno} \, \partial_i \partial_j \varphi_l \, \partial_m \partial_n \varphi_o$$

+ higher order ....

$$V = \int d^3x \left[C_{ijlm} \nabla_i \varphi_j \nabla_l \varphi_m + \underline{C_{ijlmno} \partial_i \partial_j \varphi_l \partial_m \partial_n \varphi_o} + \dots \right]$$

Truncate $+ \dots$

How big is C_{ijlm}??

V is an energy eV

d^3x length^3 Å or nm cubed

φ length $\nabla\varphi \nabla\varphi$ dimensionless

∂_i inv. length $\nabla\nabla\varphi\nabla\nabla\varphi$ has dim. $(\text{length})^{-2}$

$$C_{ijlm} \sim \frac{[V]}{[d^3x][\partial^2][\varphi^2]} \sim \frac{\text{eV}}{\text{Å}^3}$$

Examine scales large vs. 1 Å

$$C_{ijlmno} \sim \frac{[V]}{[d^3x][\partial^4][\varphi^2]} \sim \frac{\text{eV}}{\text{Å}^5} \text{ — suppressed by } \left(\frac{1\,\text{Å}}{\lambda}\right)^2$$

General lessons:

Energy, L, action S depend on <u>fields</u>

(value at each pt. in space)

$$S = \underbrace{\int dt \int d^3x}_{\text{space-time}} \; \mathcal{L}(\varphi, \underbrace{\partial_t \varphi, \nabla \varphi}_{\partial_\mu \varphi})$$

$\mathcal{L}$ can have inf. # of possible terms

<u>BUT</u> not all <u>important</u> — Scales & Dimensions,

fund. scales in problem — organize into

- important (Relevant)
- <u>irrelevant</u> int's.

Don't worry #DOF appears to be ∞

Somewhere at back of minds, imagine <u>space is "grainy"</u>

$\Rightarrow S = \int dt\, L = \underbrace{\int dt \int d^3x}_{d^4x \text{ spacetime}}\, \mathcal{L}(\varphi, \partial_\mu \varphi)$

looks (is) covariant — $t, \vec{x}$ enter on same footing

4-deriv.

S formulation natural — capture (Lorentz) symm.

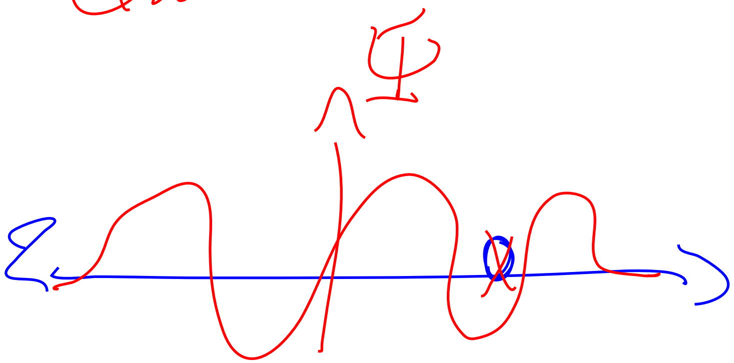
H of QM: e^{-iHt}

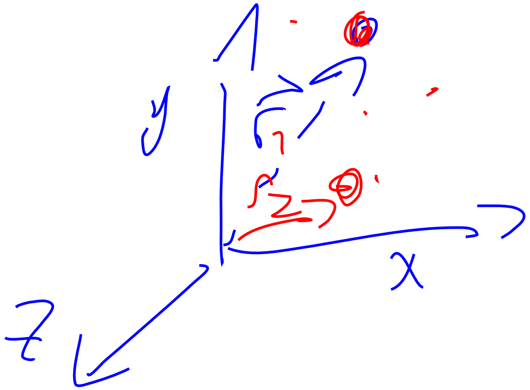
$H = \int d^3x\, \mathcal{H}(\varphi, \vec{\nabla}\varphi, \cancel{\partial_0 \varphi})$, π

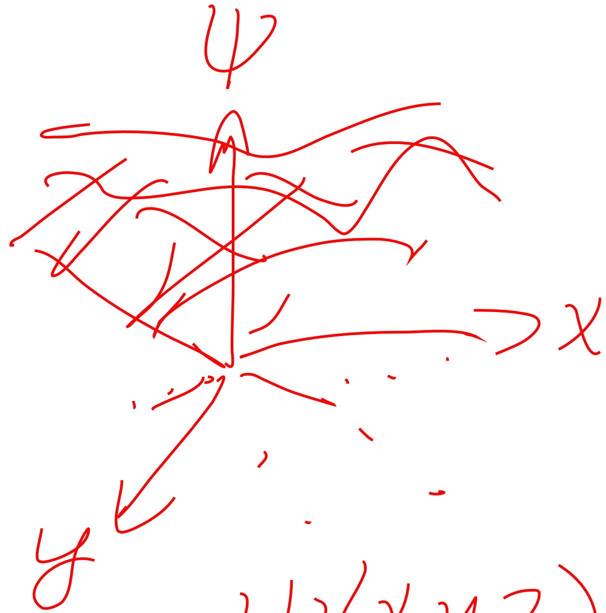
Non-covariant formulation.

Not wrong, but less convenient

Class. Mechanics 1 Dim
Quant. " "







$\langle x | \psi \rangle = \psi(x)$

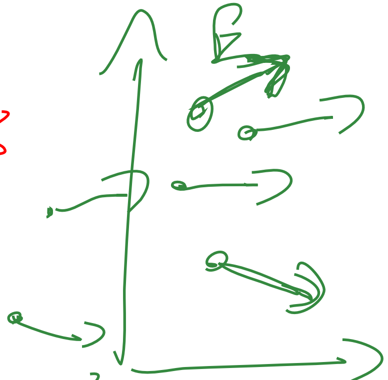
$\psi(x,y,z)$

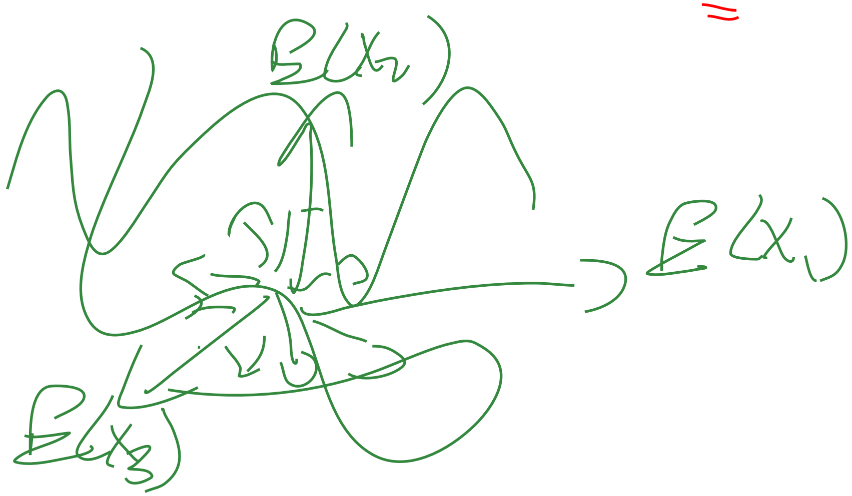
$\vec{x}$ ~~answer~~ variable

$\langle xyz | \psi \rangle = \psi(x,y,z)$

$\langle x_1 y_1 z_1 x_2 y_2 z_2 | \psi \rangle = \psi(\vec{x}_1, \vec{x}_2)$

wave func. over possible class. configs





$\langle \underbrace{\text{class. allowed}}_{E} | \psi \rangle = \Psi(E)$