SUSY Lectures in 2017 Summer

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1 Introduction

1) [L1] Quantum Field Theory

: basic framework to study elementary particles and their interactions.

"special relativity + Quantum mechanics"

$$\text{On special relativity} \quad \begin{cases} \text{spacetime} : (ct, \vec{x}) \\ \text{force: mediated by fields. (e.g. EM)} \end{cases}$$

S: action
$\delta S = 0$: classical action(least action)

$$\langle f|i\rangle \sim \sum_{\text{path}} e^{iS/\hbar} \quad ; \text{path integral}$$

$$\begin{cases} \Delta S \gg \hbar & ; \text{Classical} \\ \Delta S \sim \hbar & ; \text{Quantum} \end{cases}$$

We use the natural unit, $\hbar = c = 1$.

$$\text{Theory} \quad \begin{cases} \text{action}(S) \\ \quad + \\ \text{regularization} \\ \quad + \\ \text{renormalization} \end{cases}$$

1-a) S(action)

$$S = \int \underbrace{d^4x}_{dtdxdydz} \mathcal{L}(\phi, \partial_\mu \phi)$$

where ϕ is a field, $\phi(x)$. Lagrange has a symmetry.

i) symmetry
- Important role to better understand natural.
- Defining an elementary particle according to the behavior of the corresponding field with respect to symmetries.
- Determining interactions among particles.
(can be hidden; spontaneous breaking)

Noether Theorem(classical field theory)
: continuous symmetry $\rightarrow$ conserved quantity

Symmetry

1. Spacetime Symmetry ($x \to x'$)
   (a) Poincaré Transformation: transformation leaving the line element invariant.
   $\to ds^2 = \eta_{\mu\nu} dx^\mu dx^\nu$
      i. Lorentz transformation; action conservation
      ii. Translations; energy-momentum conservation
   (b) General coordinate Transformation
   $\to$ general relativity
2. Internal Symmetry

$$\Phi^a(x) \to \Phi'^a(x) = M^a{}_b \Phi^b(x)$$

where $\Phi^a(x)$ is general field and a, b are internal indices.

$$M^a{}_b \begin{cases} \text{global symmetry: } M^a{}_b \text{ is spacetime-independent} \\ \text{local(gauge) symmetry: } M^a{}_b(x) \text{ is spacetime-dependent} \end{cases}$$

QFT: the most general symmetry of the S-matrix(Scattering matrix).

Note 1.1 *Coleman-Mandula(1967)*

$$\text{Poincaré symmetry} \bigotimes \text{Internal symmetry}$$

where $\bigotimes$ is a direct product.

- assumption on QFT (local, relativity, $4D$, ...)
  & scattering interacions.
- considered only bosonic generator.

Extended to include spinor generators(spin: $\frac{1}{2}$, $\frac{3}{2}$),

Note 1.2 *Haag-Lopuszański-Sohnius(1975)*

$$\text{Super-Poincaré symmetry} \bigotimes \text{Internal symmetry}$$

1-b) Regularization & Renormalization

1. Regularization
   (a) UV divergence
   : we need to regulate the theory.
   (Infinities $\to$ absorbed by appropriate counter terms.)
   e.g. cutoff regulation, dimensional regularization

2. Renormalization
   : determine how to absorb the infinities into counter terms.
   (arbitraty renormalization point μ(unphysical))

   (a) Perturbation Theory
       : expansion w.r.t $\underbrace{\text{renormalized parameters.}}_{\mu-\text{dep.}}$ $\rightarrow$ large logs: $\ln(\frac{E}{\mu}), \ln(\frac{M}{\mu})$
       $\rightarrow$ physical amplitude(independent of μ) $\rightarrow$ "set $\mu \sim E$"

   (b) RGE(Renormalization Group Equation)

2) [L2] Effective Field Theory