The Standard Model

Part III e 2019

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1.1 Introduction

Definition 1 (standard model)**:** A theoretical physics construction (theory, model) that describes all known elementary particles and their interactions based on relativistic quantum field theory (QFT).

Ingredients

(i) spacetime: $3+1$ dimensional Minkowski space

symmetry: Poincaré group

(ii) particles:

spin $s=0$ Higgs

spin $s=1/2$ three families of quarks and leptons

(iii) interactions:

$s=1$ three gauge interactions

$s=1$ gravity[2]

Gauge (local) symmetry: $SU(3)_C \times SU(2)_L \times U(1)_Y \xrightarrow[Breaking]{Symmetry} SU(3)_C \times U(1)_{EM}$

C color: strong

L left: electroweak

Y hypercharge

These are related via $Q = T_3 + Y$.

Particle representations[3]:

[2] as important as it is, we will not be concerned with gravity for most of this course

[3] numbers tell us representations under $(C, L; Y)$

- Quarks and Leptons: $\overbrace{3}^{\text{families (flavour)}}[\underbrace{(3,2;\frac{1}{6})}_{Q_L}+\underbrace{(\bar{3},1;-\frac{2}{3})}_{U_R}+\underbrace{(\bar{3},1;\frac{1}{3})}_{d_R}+\underbrace{(1,2;-\frac{1}{2})}_{L_L}+\underbrace{(1,1;1)}_{e_R}+\underbrace{(1,1;0)}_{\nu_R}]$
- Higgs: $(1,2;-\frac{1}{2})$
- Gauge: $\underbrace{(8,1;0)}_{gluons}+\underbrace{(1,3;0)}_{W^{\pm},\mathbb{Z}}+\underbrace{(1,1;0)}_{\gamma}$

Comments

- interactions given by QFT
- main tool: symmetry
- total symmetry: spacetime $\otimes$ internal (gauge)[1]
- also accidental (global) symmetries $\sim$ baryon + lepton number
- plus approximate (flavour) symmetries:
- very rigid: $\sum Y = \sum Y^3 = 0$[2], $\#3 = \#\bar{3}$, #2 even
- rich structure (3 phases: Coulomb, Higgs, confining)

Motivation

Why to learn about the SM?

- It is fundamental.
- It is based on elegant principles of symmetry.
- It is true!
  - outstanding predictions: ($\mathbb{Z}^0, W^{\pm}$, Higgs, …)
  - precision tests:
    anomalous magnetic dipole moment of the electron:

$$a = \frac{g-2}{2} = (1159.65218091 \pm 0.00000026) \times 10^{-6} \tag{1.1}$$

[1] Theorem: cannot mix these two symmetries. Supersymmetry provides a way around this.
[2] gravitational anomaly

fine structure constant (at $E \ll 10^3$GeV):

$$\alpha^{-1} = \frac{\hbar c}{e^2} = 137.035999084(21) \tag{1.2}$$

- It is the best test of QFT.
- It is incomplete!