SCPY322 Nuclear and Particle Physics

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Lecture 5. Friday 29, April 2021

Reviews of the Last Lecture

We have constructed quark models of hadrons from su(2) and su(3) algebras. Now, as we think, we have complete picture of nature from its building block of elementary particles, i.e., leptons and quarks.

7 The Standard Model and Fundamental Interactions

7.1 The standard model particles

List of the standard model of elementary particles.

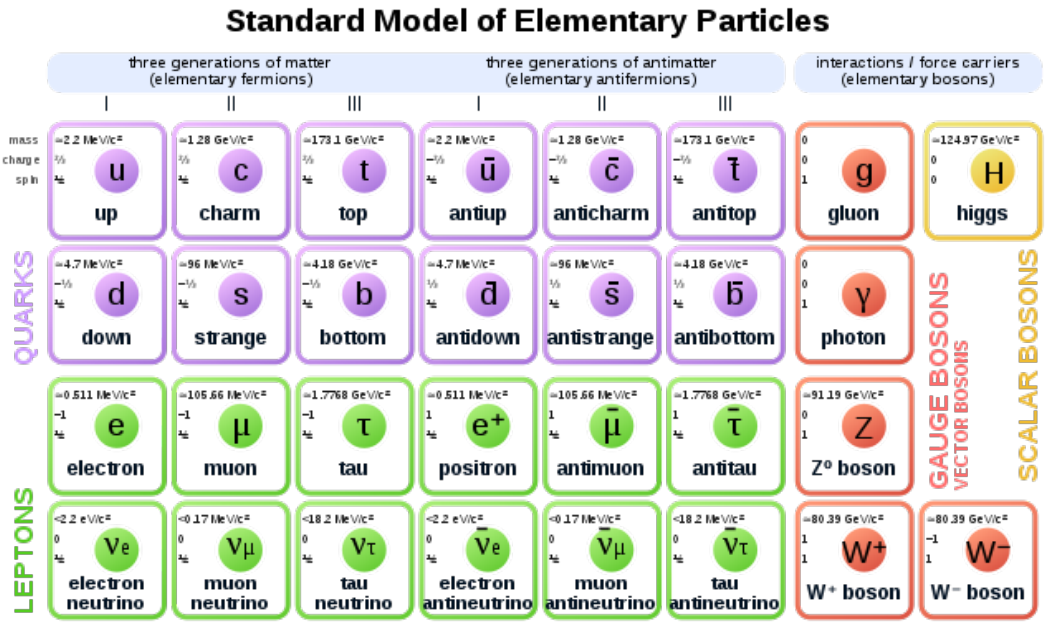

Figure 1:

Leptons and quarks appear in 6 flavors, and grouped in three generations. The fundamental interactions is describe by exchange particle of force fields,

vector of gauge fields, except gravity. Extra Higgs particle is added in order to break gauge symmetry (spontaneously) and produce gauge field particle masses.

More information of the standard model particles:

	symbol	name	mass (MeV/c^2)	charge (e)
Quarks	d	down	≈ 10	$-1/3$
(spin = 1/2)	u	up	≈ 5	2/3
	s	strange	≈ 200	$-1/3$
	c	charm	≈ 1500	2/3
	b	bottom	≈ 4500	$-1/3$
	t	top	$\approx 175 - 200$ GeV/c^2	2/3
Leptons	e	electron	0.511	-1
(spin=1/2)	ν_e	electron neutrino	< 7 eV	0
	μ	muon	105.7	-1
	ν_μ	muon neutrino	< 0.27	0
	τ	tau	1777	-1
	ν_τ[a]	tau neutrino	< 31	0
Gauge bosons	γ	photon	0	0
(spin = 1)	W	W	80.2 GeV/c^2	1
	Z	Z	91.2 GeV/c^2	0
	g	gluon	0	0
Higgs	H[b]	Higgs	?	?

[a]Not yet definitively observed.

[b]Not yet observerved.

Figure 2:

7.2 Fundamental interactions

Property	Fundamental Interaction			
	Gravitational	Electromagnetic	Weak	Strong
Field Bosons	graviton	photon	W^+, W^-, and Z^o	8 gluons
Mass of Field Boson (GeV/c^2)	0	0	$M_W = 80.4$ $M_Z = 91.2$	0
Range of the interaction (m)	∞	∞	10^{-18}	$\leq 10^{-15}$
Source of the interaction	mass	electric charge	weak currents	color charge
Strength (Relative to the Strong Interaction)	10^{-39}	10^{-2}	10^{-5}	1
Typical Cross Section (m^2)	[a]	10^{-33}	10^{-39}	10^{-30}
Typical Lifetime (s)	[a]	10^{-20}	10^{-10}	10^{-23}

[a] In view of the range and source of the gravitational interaction, the cross section and lifetime are not well-defined quantities.

Figure 3:

7.3 Toy model of particle interaction

Gauge symmetry of vector fields

$$A^\mu(x) = (\phi(x), \vec{A}(x)) \to \vec{B} = \nabla \times \vec{A},\ \vec{E} = -\nabla\phi - \partial_t \vec{A} \tag{1}$$

$$\partial^\mu = (\partial_t, -\nabla) \to \partial^\mu A^\nu - \partial^\nu A^\mu = F^{\mu\nu} - \text{field strength tensor} \tag{2}$$

$$F^{\mu\nu} = \begin{bmatrix} 0 & -E_x/c & -E_y/c & -E_z/c \\ E_x/c & 0 & -B_z & B_y \\ E_y/c & B_z & 0 & -B_x \\ E_z/c & -B_y & B_x & 0 \end{bmatrix}$$

Gauge symmetry of the vector (gauge) field

$$A^\mu \to \partial^\mu \alpha(x),\ F^{\mu\nu} \to F^{\mu\nu} \tag{3}$$

Gauge field interaction in CM and QM

- Hamiltonian of a charged particle moving in the presence of the electromagnetic field is given by

$$H = \frac{1}{2m}(\vec{p} - q\vec{A})^2 + q\phi$$

- Quantum mechanically, the charged particle is described by the Schrödinger equation,

$$-\frac{1}{2m}\left(\nabla - iq\vec{A}\right)^2 \psi(\vec{x}, t) = i\left(\frac{\partial}{\partial t} + iq\phi\right)\psi(\vec{x}, t)$$

Figure 4:

Yukawa *exchange interaction*, and Feynman diagram, with energy-momentum conservation

$$p + p' = k + k' \;\; p' = p - q, k' = k + q$$

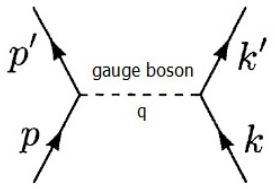

Figure 5: