Elementary Particle Physics II (8802.02)

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grading: based on HWs ← once in 1-2 weeks

class notes: online

syllabus: online

textbook: T.-P. Cheng & L.-F. Li
"Gauge Theory of Elementary Particle Physics"
more listed on-line

Exams: by request

Brief Review of First Semester

I will not review the parts of the 1st semester which were QFT. Consider QFT as our main tool, but the subject will be particle physics.

Quark Model and Group Theory

~ defined <u>isospin</u> operator $\vec{I} \Rightarrow \vec{I}^2, I_z$ have eigenvalues $I(I+1)$ and $-I, \ldots, I$ correspondingly (p, n or π^+, π^0, π^-, etc.)

~ defined <u>baryon #</u> : # of Baryons (B)

~ <u>strangeness</u>: $\underbrace{K^+, K^0}_{S=+1}, \underbrace{\bar{K}^0, K^-}_{S=-1}$

$$Q = I_3 + \frac{Y}{2}$$

(Q: electric charge; Gell-Mann–Nishijima)

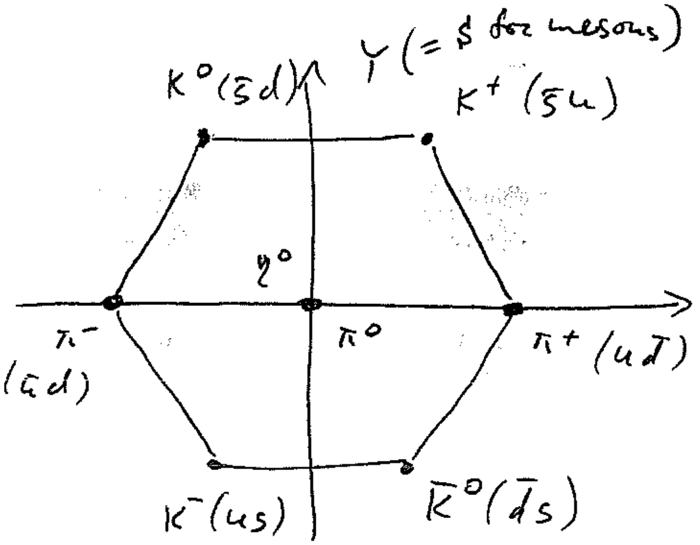
~ <u>hyper charge</u>: $Y \equiv B + S$

"Eight fold Way":

$$\pi^0 = \frac{\bar{u}u - \bar{d}d}{\sqrt{2}}$$

$$\eta^0 = \frac{1}{\sqrt{6}}\left(\bar{u}u + \bar{d}d - 2\bar{s}s\right)$$

0^- mesons (pseudoscalar mesons)



Gell-Mann & Ne'eman ('61) Zweig

Quarks: u, d, s, c, b, t

have $Q = +2/3$ or $-1/3$, $B = +1/3$, u,d have $I = \frac{1}{2}$, $I_z = \left(\begin{smallmatrix}+\frac{1}{2} \\ -\frac{1}{2}\end{smallmatrix}\right.$

s-quark has $S = -1$.

~ another quantum #: <u>color</u> $i = 1, 2, 3$

$\Rightarrow$ $u_i(x)$ ~ 3 colors of up quark.

mesons, baryons ~ always color-neutral!

$\Rightarrow$ quarks interact with each other by exchanging gluons ~ spin-1 non-Abelian gauge fields: A_μ^a, $a = 1, \ldots, 8$ ~ gluon color $SU(3)_c$

quark fields: q^{if} (i ← color, f ← flavor).

$$\mathcal{L}_{QCD} = \bar{q}^{if}(i\gamma\cdot\partial - m_f)q^{if} - \frac{1}{4}F_{\mu\nu}^a F^{a\mu\nu} + g\,\bar{q}^{jf}\gamma^\mu A_\mu^a (T^a)_{ji}\, q^{if}$$

with T^a the generators of group $SU(3)$ in the fundamental representation: $T^a = \frac{\lambda^a}{2}$

λ^a ~ Gell-Mann matrices

$[T^a, T^b] = i f^{abc} T^c$, f^{abc} ~ $SU(3)$ structure constants.

gluon field strength:

$$F_{\mu\nu}^a = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + g f^{abc} A_\mu^b A_\nu^c$$

defining $A_\mu = \sum_{a=1}^{8} A_\mu^a T^a$ & defining the covariant derivative $D_\mu = \partial_\mu - ig A_\mu$ get

$$\mathcal{L}_{QCD} = \bar{q}^f (i \gamma \cdot D - m_f) q^f - \frac{1}{4} F_{\mu\nu}^a F^{a\mu\nu}$$

~ We studied group theory. In particular for SU(3) we showed that the following is true:

$$3 \otimes \bar{3} = 1 \oplus 8$$

$$3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10$$

⇒ for <u>mesons</u> made out of u, d, s quarks due to $3 \otimes \bar{3} = 1 \oplus 8$ get a flavor-octet. η' ~ singlet.

<u>Baryons</u>: $3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10$ ⇒ have an octet and a decuplet ~ all agrees with experiment.

~ also works for colors.

Quark-only Lagrangian: $N_f = 3$

$$\mathcal{L} = \bar{q}\,(i\gamma\cdot\partial - m)\,q\ ,\quad q = \begin{pmatrix} u \\ d \\ s \end{pmatrix}\ ,\quad m = \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & m_s \end{pmatrix}$$

=> defined $\quad q_L = \dfrac{1-\gamma_5}{2}\,q\ ,\quad q_R = \dfrac{1\!\!1+\gamma_5}{2}\,q$

$$\Rightarrow\ \mathcal{L}_{m=0} = \bar{q}_L\, i\gamma\cdot\partial\, q_L + \bar{q}_R\, i\gamma\cdot\partial\, q_R$$

=> $SU(3)_L \otimes SU(3)_R$ invariant! $\quad q_L \to e^{i\vec{\alpha}_L\cdot\vec{T}}\, q_L$

chiral symmetry

add mass but with $m = m_u = m_d = m_s$ =>

get $\mathcal{L} = \bar{q}_L i\gamma\cdot\partial q_L + \bar{q}_R i\gamma\cdot\partial q_R - m\,[\bar{q}_L q_R + \bar{q}_R q_L]$

=> $SU(3)_L \otimes SU(3)_R$ is broken down to $SU(3)$.

if $m_u \neq m_d \neq m_s$ $\quad SU(3)$ is also broken: