Standard model of elementary particles and interactions

G Kane Modern elementary particle physics
Addison - Wesley Pub 1987

Zoo

1. Forces

1. Gravity (classical)

2. Electrodynamics

   QED (1935, 1949, ~ 1950

3. Weak interaction

   Fermi ~1940

   Weinberg-Salam ~ 1970

4. Strong interaction

   QCD ~ 1975

2. Particlse producing forces

Bosons

1.	Graviton		$S = 2$	$m = 0$
2.	Photon	γ	$S = 1$	$m = 0$
3.	$W^{\pm}$, Z - bozons		$S = 1$	$m \sim 80$ Gev
4.	Gluons	g	$S = 1$	$m = 0$ confinemen

	QED	W-S	QCD	
Boson	γ	$W^{\pm}, Z$	g	Gauge
number	1	3	8	bosons
gauge Symmetry	$U(1)$	$SU(2)$	$SU(3)$	
Phase	Coulomb	Higgs	Confinment	$U(1) \times SU(2) \times SU($

3. Fermions

Leptons

$\begin{pmatrix} \nu_e \\ e \end{pmatrix}$ $\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$ $\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$ $q = 0$ $q = -e$

$m_{\nu_e} < 10\,eV$ $m_{\nu_\mu} < 250\,eV$ $m_{\mu\tau} < 70\,Me$

$m_e = 0.511\,MeV$ $m_\mu \sim 100\,MeV$ $m_\tau \sim 2\,GeV$

$\begin{pmatrix} \nu_e \\ e_L \end{pmatrix}$ ← interacts with $W^{(\pm)}$

e_L, e_R - left and right chiralities

e_R

Quarks

$\begin{pmatrix} u \\ d \end{pmatrix}$ $\begin{pmatrix} c \\ s \end{pmatrix}$ $\begin{pmatrix} t \\ b \end{pmatrix}$ $q = \frac{2}{3} e$

$q = -\frac{1}{3}$

3 Colours $q = \begin{pmatrix} q_1 \\ q_2 \\ q_3 \end{pmatrix}$ ← Colours

↖ Colour space (Isotopic space)

$m_u \sim m_d \sim 5$ Mev

$m_s \sim 200$ Mev

$m_c \sim 1.5$ Gev

$m_b \sim 5$ Gev

$m_t \sim 150$ Gev

3 Generations of fermions

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} b \\ t \end{pmatrix}$$

+ antiparticles

4. Elementary particles

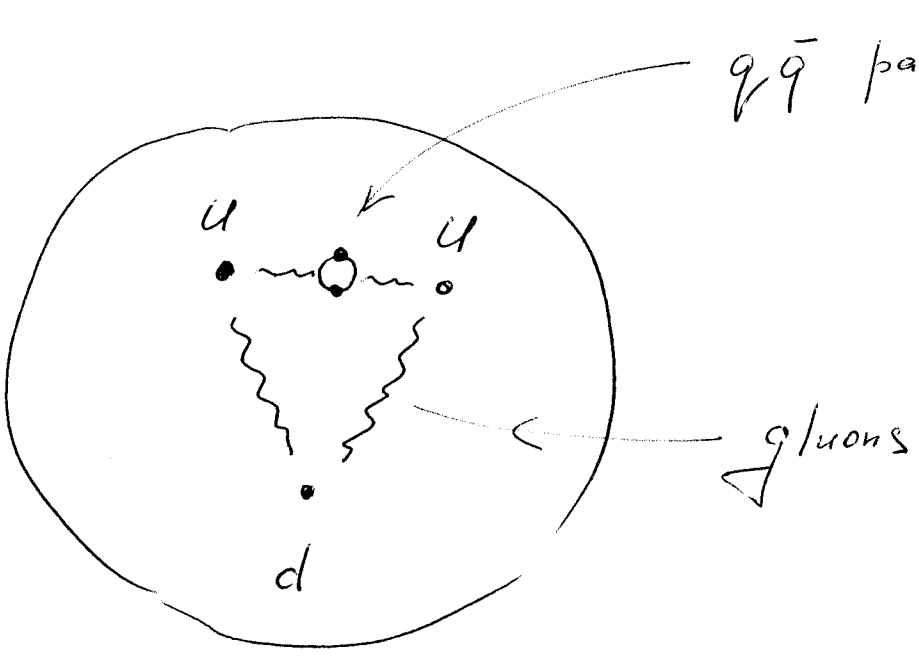
Barions

Fermions

$B = qqq$ $\quad S = \frac{1}{2}, \frac{3}{2} \ldots$

$p = uud$

$n = udd$



Mesons

Bosons

$M = q\bar{q}$ $\quad S = 0, 1 \ldots$

$S = 0$ → Scalar mesons

$S = 1$ → Vector mesons

$\pi^+ = u\bar{d}$

$\pi^- = \bar{u}d$

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

Confinement

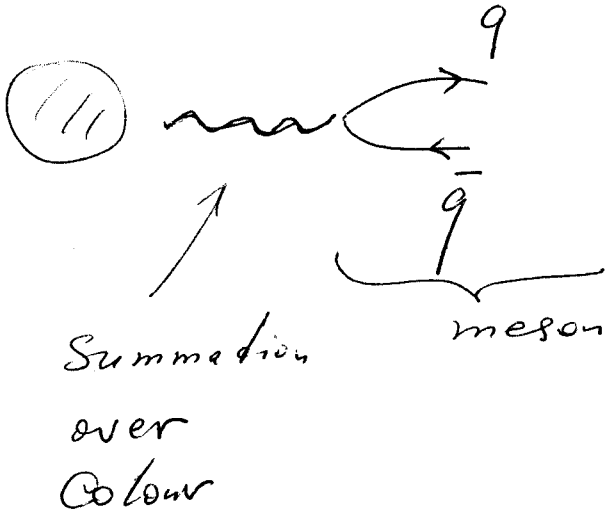
Quarks and gluons live only inside elementary particles

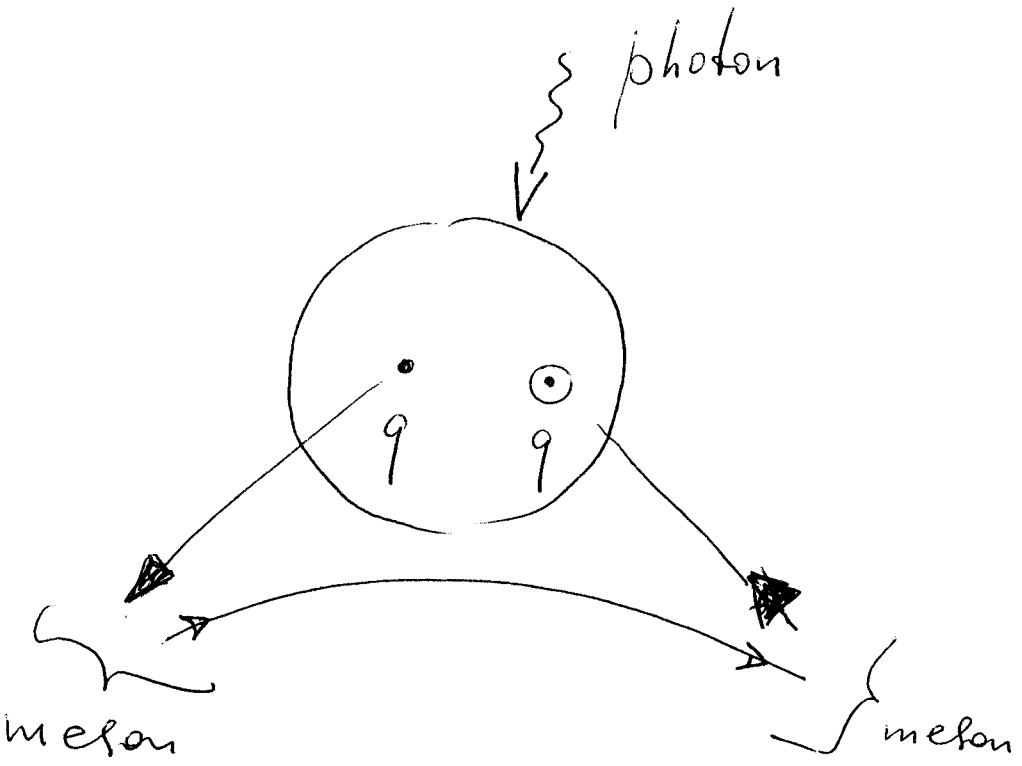
A stable (more or less) particle cannot have colour

$$B = \epsilon_{ijk} q_i q_j q_k$$

$$M = q_i \bar{q}_i$$

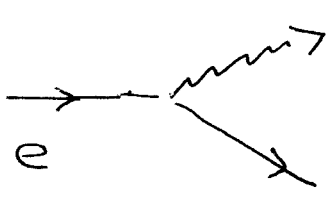
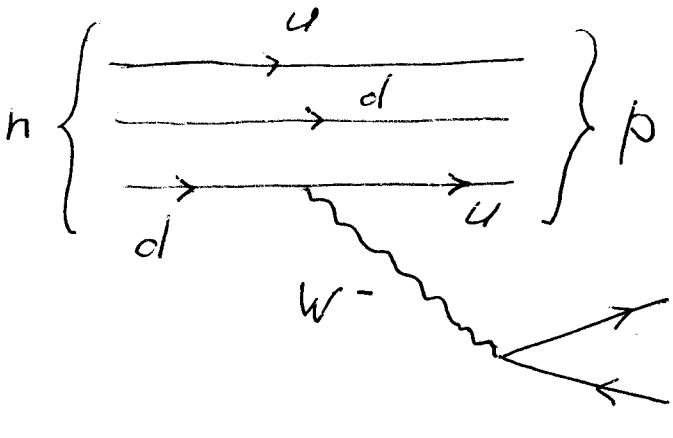

impossible
gluon


q
q̄
Summation
over
Colour
meson


photon
q
q
meson
meson

5. Conservation laws

Continuous symmetries

Cons. Law	Symmetry, example
Energy	t - translation
Momentum	r - translation
Orbital Momentum + Spin	rotation
Charge	Global gauge transformation $\psi \to e^{i\alpha}\psi$ α = Const
Lepton number	
Barion number	

Discrete symmetries

P , T , C

CPT — exact

P — "approximate" symmetry
violated by Weak Interact

CP
T — "approximate" symmetry
violated by SuperWeak Int

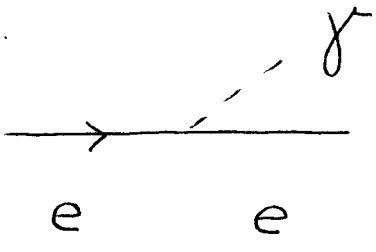
K mesons decay

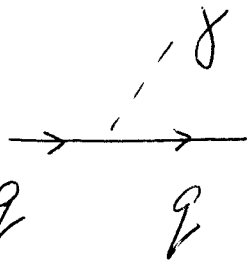
6. Radius of Interaction

	Force	Phase	Law	Radius
	Gravity		$\sim \frac{1}{r}$	$r = \infty$
Gauge Theories	QED	Coulomb phase	$\sim \frac{1}{r}$	$r = \infty$
	Weak Int	Higgs phase	$\sim \frac{e^{-mr}}{r}$ $m \sim m_W, m_Z$	$r = \frac{1}{m_W}$
	QCD	Confinement phase	$\sim \frac{1}{r}$ $r \to 0$ $\sim kr$ $r > \frac{1}{\Lambda_c}$	$r = \frac{1}{\Lambda_c}$ $\Lambda_c = 100\text{-}300$ Mev

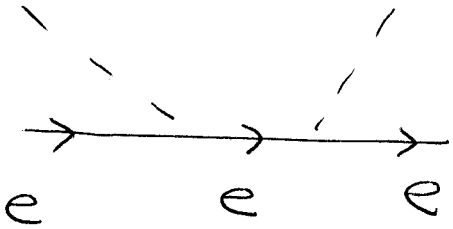
Examples

QED





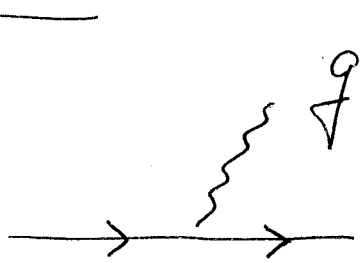
virtual processes



real process

$e + \gamma \rightarrow e + g$

QCD



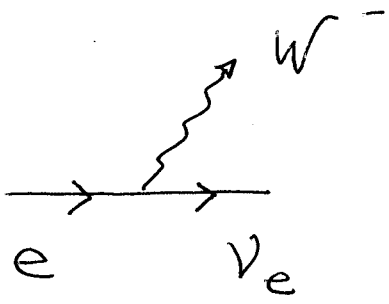
(8 colours)

(3 colours)

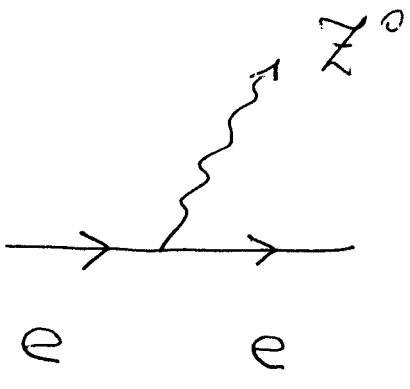
Week Interaction

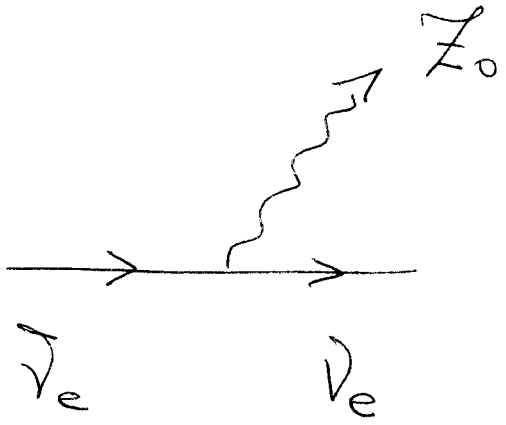
Leptons

- Charged currents



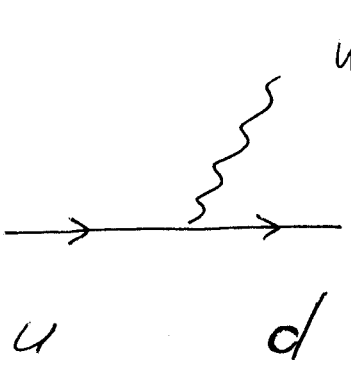
- Neutral currents





Quarks

- Charged currents



$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix}$$

Cabibbo

$$d' = \cos\theta_c\, d + \sin\theta_c\, s + \dots$$

$$s' = -\sin\theta_c\, d + \cos\theta_c\, d + \dots$$

$$\theta_c \simeq 13^\circ$$

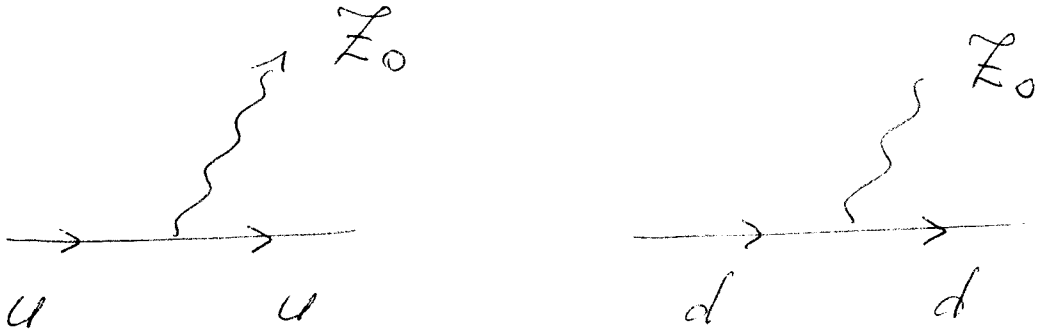
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} & U & \\ & & \\ & & \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Kobayashi Maskawa

U has 1 phase parameter $e^{i\delta}$

It makes the theory non-invariant to T transformations

- Neutral Currents



8 Renormalizability

Renormalizability <=>

Perturbation theory is applicable

Gauge theories: the only class of renormalizable theories.