\[ U_{em} = \frac{e^2}{r} \times \left( \frac{1}{4\pi \varepsilon_0} \right) \frac{1}{\varepsilon_0} \]

\[ e_{em} = \frac{\hbar c}{r} \]

Quarks have non-zero \( e_c \)

Leptons \( \left( e^-, \mu^-, \nu_1, \nu_2, \nu_3 \right) \) + antiparticles

Photon; \( Z^0, W^\pm \) zero \( e_c \)

The Gluon: non-zero \( e_c \)

\( e_c \): more complicated than electric charge

\( f \) value (real #), antiparticles...
3 values (like 3 dim vector) called: Red, Green, Blue
antiquarks: \( \bar{R}, \bar{G}, \bar{B} \)

\[ |e_R| = |e_G| \text{ since } \alpha_s \gg \alpha \]

Magnitude \( |e| \) always same but in principle could have different components along \( R, G, B \) directions usually just talk about ind colors

Key point: colorless combinations of quarks lowest in energy

Mesons:

\[ \chi \]

\[ C \text{ glue field} \]

\[ q_1(B) \] \quad \[ \bar{q}_2(B) \]

\[ R \] \quad \[ \bar{R} \]

\[ G \] \quad \[ \bar{G} \]

\[ \text{color/anticolor totally canceled} \]

Higher in energy
Baryons:

\[ q_1 \ (B) \ \{ \begin{array}{c} q_2 \ (R) \\ G \end{array} \ \} \]

3 colors totally correlated

RGB \rightarrow \text{"White"} \rightarrow \text{colorless}

Other color permutations?

Gluon: a color, an anticolor

\[ \begin{array}{c} R \\ G \end{array} \]

3 \times 2 = 6 different colors

"spring"

"octet"

8 gluons

"The glue"

The force carrier interacts with itself

"GLUE" very complicated
Visualization & Feynman Diagrams

\[ H_{\text{total}} = H_{\text{strong}} + H_{\text{em}} + H_{\text{weak}} + H_{\text{grav}} \]

\[ H_{\text{em}} \] huge \( \rightarrow \) OK
\[ H_{\text{weak}} \] neutrinos

Conceptually:

Often work in eigenstates of
\[ H_{\text{strong}}, H_{\text{strong}} + H_{\text{em}} \]
\[ H_{\text{em}} + H_{\text{weak}} \] weak a perturbation
perturbation Table of Fermions

\[
\begin{array}{c|ccc}
\nu & s & t & (1790) \\
\hline
d & c & b & (430) \\
e^- & \mu^- & \tau^- & (178) \\
\gamma & 0 & \gamma_2 & 0 & \gamma_3 & 0 \\
\end{array}
\]

all totally stable, 'eigenstates'

It weak neglected... not excitations
Feynman Art:

1. Turn off all interactions
2. Introduce time

\[ \text{unbroken line is like a conserved electric current} \]

\[ \text{electric charge...} \]

OTHERS: (in absence of weak)

- Quark

- Lepton number