- they attract!
- when close...

$q\bar{q}$ attract too!

$$U_{em} = \underbrace{\frac{e^2}{r}}_{\text{cgs}} \times \left(\underset{\overset{\uparrow}{\text{HL}}}{\frac{1}{4\pi}} \; \underset{\overset{\uparrow}{\text{MKS only}}}{\frac{1}{\varepsilon_0}} \right)$$

$$= \underbrace{\left(\boxed{\frac{1}{4\pi}\frac{1}{\varepsilon_0}} \frac{e^2}{\hbar c} \right)}_{\alpha_{em}} \frac{\hbar c}{r}$$

$$= \alpha_{em} \frac{\hbar c}{r}$$

$$U = \alpha_s \frac{\hbar c}{r}$$

$$= \frac{e_c^2}{\hbar c}$$ e_c = "color charge"

Quarks have non-zero e_c

<u>Leptons</u> (e^-, μ^-, τ^-, ν_1, ν_2, ν_3 + antiparticles)

<u>Photon</u>, Z^0, $W^\pm$ ... zero e_c

<u>The Gluon</u>: non-zero e_c

<u>e_c</u>: more complicated than <u>electric charge</u>

↓

<u>1 value</u> (real #), antiparticles... −

e_c : 3 values (like 3 dim vector).

called : Red, Green, Blue.

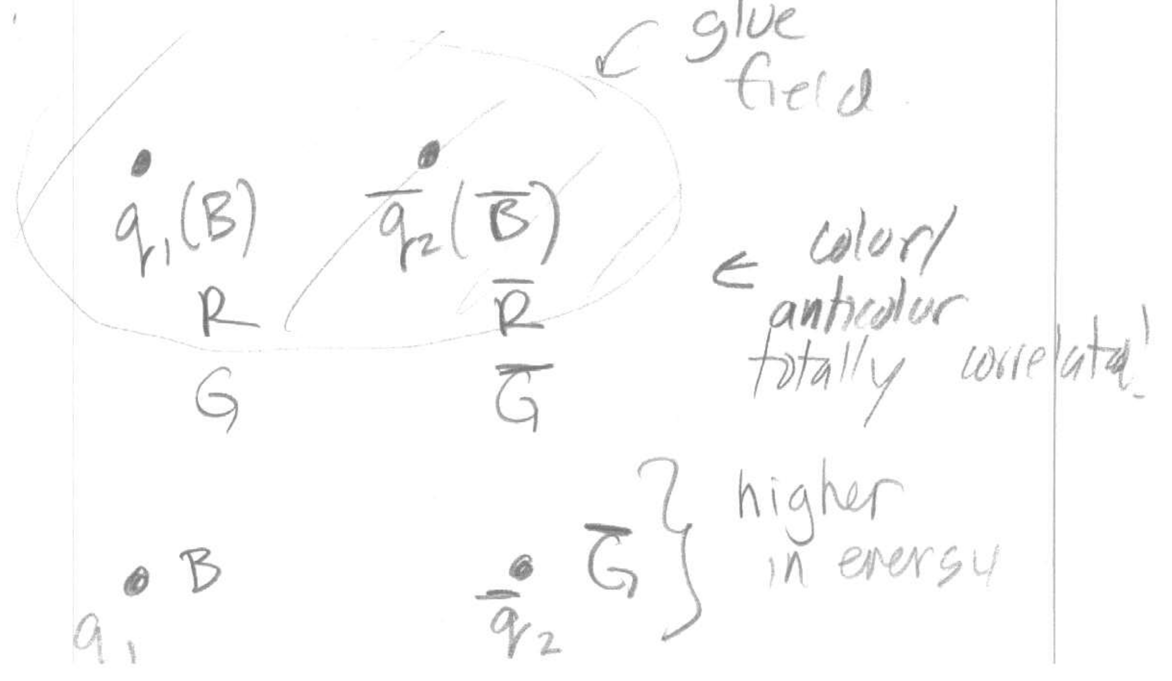
antiquarks : $\bar{R}$, $\bar{G}$, $\bar{B}$

$|e_c| \gg |e|$ since $\alpha_s \gg \alpha$

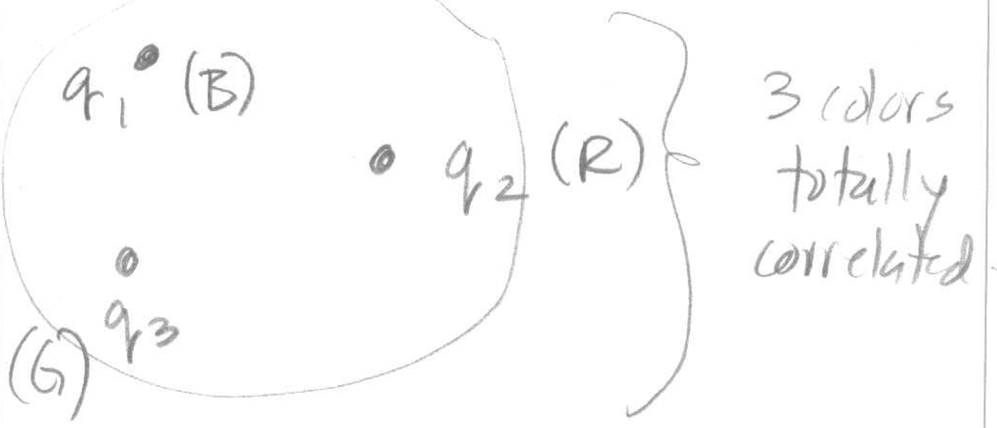
Magnitude $|e_c|$ always same, but in principle could have different components along R, G, B directions... usually just talk about ind colors.

Key point : colorless combinations of quarks lowest in energy.

Mesons :



Baryons:



RGB → "White" → colorless.

other color permutations?

Gluon: a color, an anticolor.

$\frac{R}{\bar{G}}$ } 3·2 = 6 different colors

3 ... same colors

↙ ↘

2 "ok" 1 bad

"octet" "singlet gluon" more later.

8 gluons

"The glue"

The force carrier interacts with itself! "QCD" very complicated!

Visualization & Feynman Diagrams

$$\underset{\substack{\uparrow\\ \text{everything}}}{\underline{\underset{\sim}{H}_{total}}} = \underbrace{\underset{\sim}{H}_{strong}}_{\substack{\alpha_s \text{ huge}\\ \text{some particles}\\ \text{don't feel!}}} + \underbrace{\underset{\sim}{H}_{em}}_{\text{OK}} + \underbrace{H_{weak}}_{\substack{\downarrow\\ \text{neutrinos!}}} + \underbrace{\cancel{H}_{Grav}}_{\substack{\downarrow\\ \text{Every}\\ \text{Energy!}}}$$

Conceptually:

often work in eigenstates of

$$\underset{\sim}{H}_{strong} \;,\; \underbrace{\underset{\sim}{H}_{strong} + \underset{\sim}{H}_{em}}$$

$\downarrow$

$\underset{\sim}{H}_{em} + \underset{\sim}{H}_{weak}$ perturbation $\qquad$ $\underset{\sim}{H}_{weak}$ a perturbation.

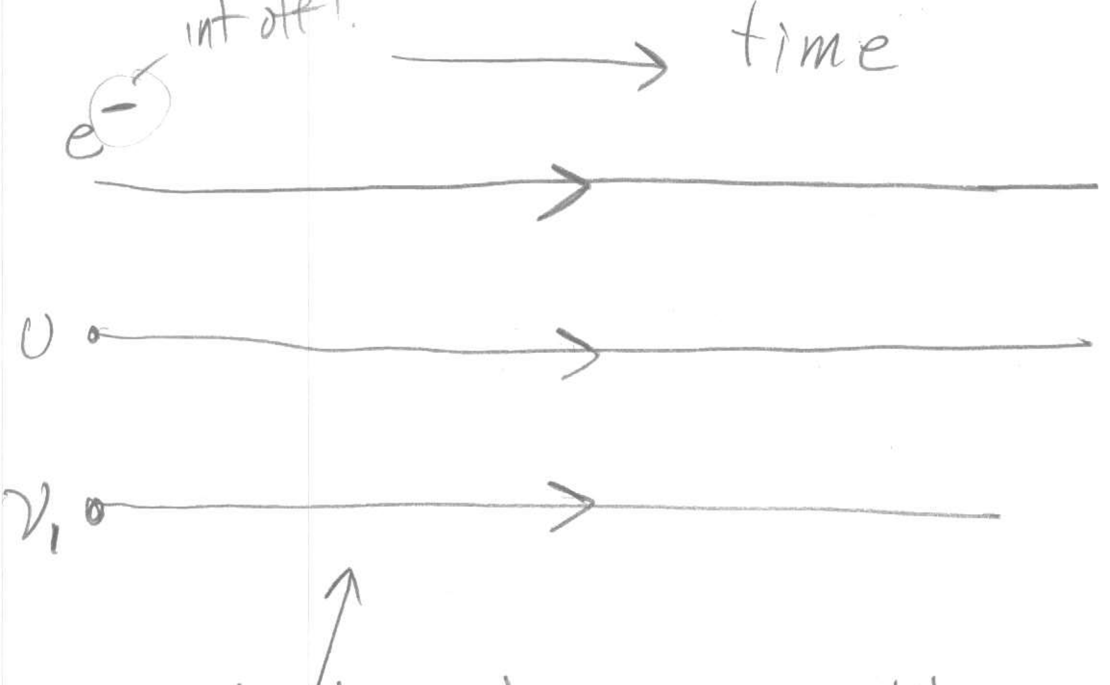
Table of Fermions

u (3)	s (120)	t (174,000)
d (7)	c (1200)	b (4300)
e^- ($\frac{1}{2}$)	μ^- (105)	τ^- (1780)
ν_1 0	ν_2 0	ν_3 0

all totally stable, "eigenstates" if $\underset{\sim}{H}_{weak}$ neglected ... not excitations

Feynman Art.....

turn off all interactions



unbroken line is *like* a conserved electric current.

electric charge...

OTHERS: (in absence of weak i)

"quark #" : u-ness, d-ness, s-ness } etc

OK even with Weak.

"lepton number" : e-ness (electron #), μ-ness (muon #), τ-ness (tau #)