Quarks and Baryons

Nojoon Myoung

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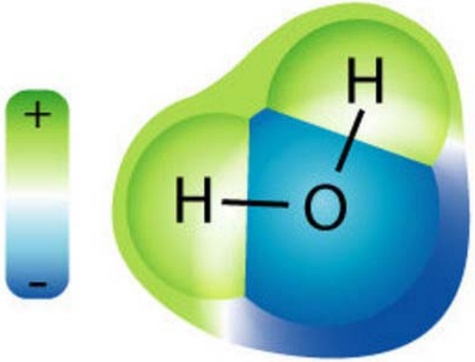
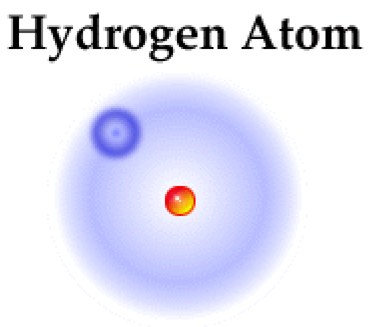
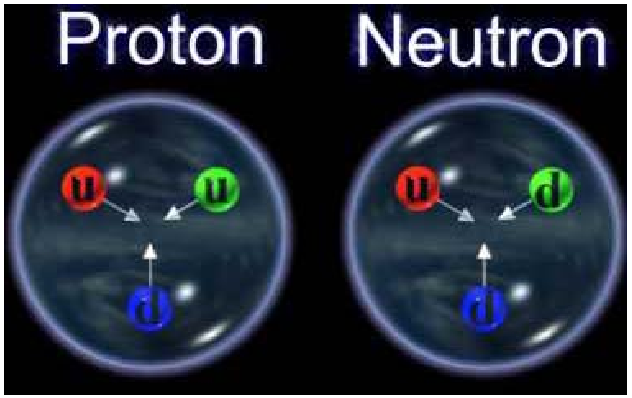
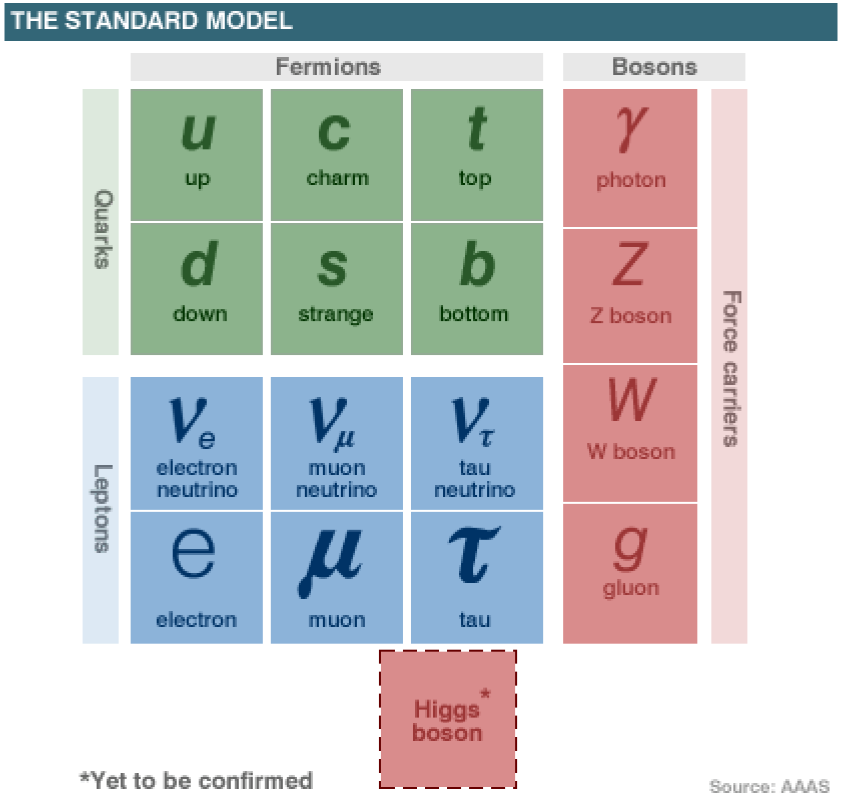
What does the matter made of?







Standard model



- six quarks
- six leptons
- four (or six) guage bosons

strongly bonded quarks by
strong interaction with gluon

Baryons and mesons

- baryon : a composite paricle which consists of three quarks

$p \rightarrow uud$ $n \rightarrow udd$ $\Lambda^0 \rightarrow uds$

$\Sigma^+ \rightarrow uds$ $\Delta^{++} \rightarrow uuu$ $\Delta^- \rightarrow ddd$

- mesons : a composite paricle which consists of quark and anti-quark

$\pi^+ \rightarrow u\overline{d}$ $K0 \rightarrow u\overline{s}$ $J/\psi \rightarrow c\overline{c}$

Milestones of quark models

• firstly proposed by Gell-mann and Zweig in 1964 : three kinds of quarks, the eightfold way (Gell-mann)

• extention to the Gell-mann-Zweig model by Glashow and Bjorken in 1964 : charm quark

• validation of Gell-man-Zweig model by SLAC experiment in 1968 : partons (Feynman)

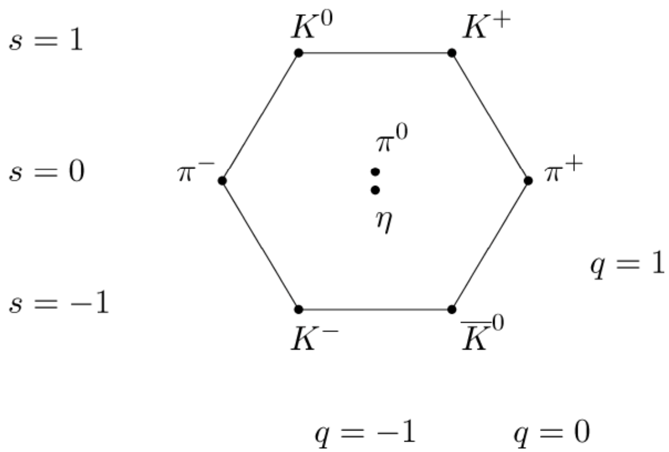
• prediction of six quarks model by Kobayashi and Maskawa in 1973 : top and bottom (Harai, 1975)

• observation of charm quark at SLAC and BNL almost simultaneously

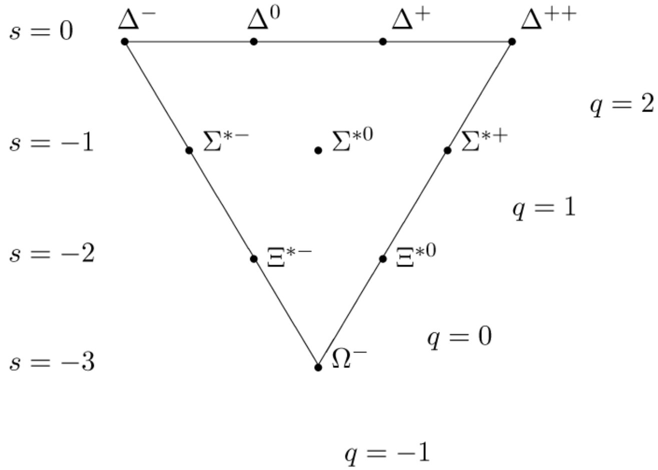
• observation of bottom (1977) and top (1995) quark at Fermilab

The eightfold way

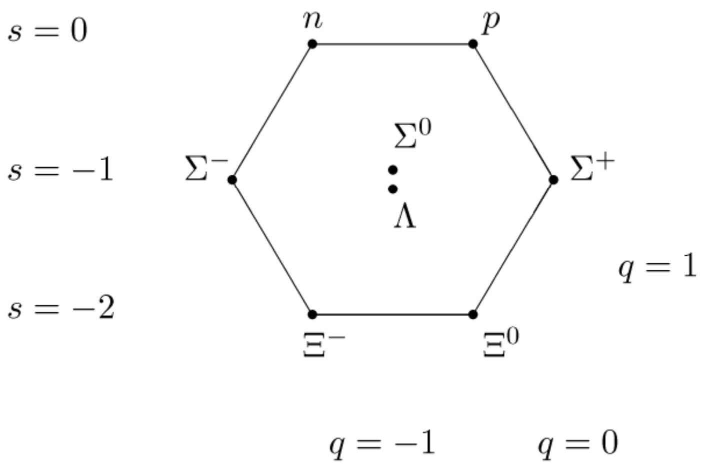
meson octet



baryon triplet



baryon octet



Color charge

• three parellel quarks within one baryon : contradiction aginst Pauli's principle

$\Delta^{++} \rightarrow uuu \qquad \Delta^{-} \rightarrow ddd$

• an additional degree of freedom by Han and Greenburg (independently) : SU(3) group with Gell-mann matrix and color charge

$$\lambda_1 = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \lambda_2 = \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \lambda_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

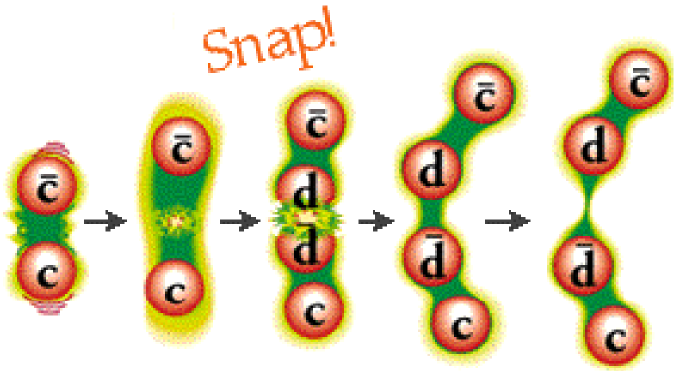
$$\lambda_4 = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \quad \lambda_5 = \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix} \quad \lambda_6 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \qquad \psi = \begin{pmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \end{pmatrix} \text{ and } \overline{\psi} = \begin{pmatrix} \overline{\psi}_1^* \\ \overline{\psi}_2^* \\ \overline{\psi}_3^* \end{pmatrix}$$

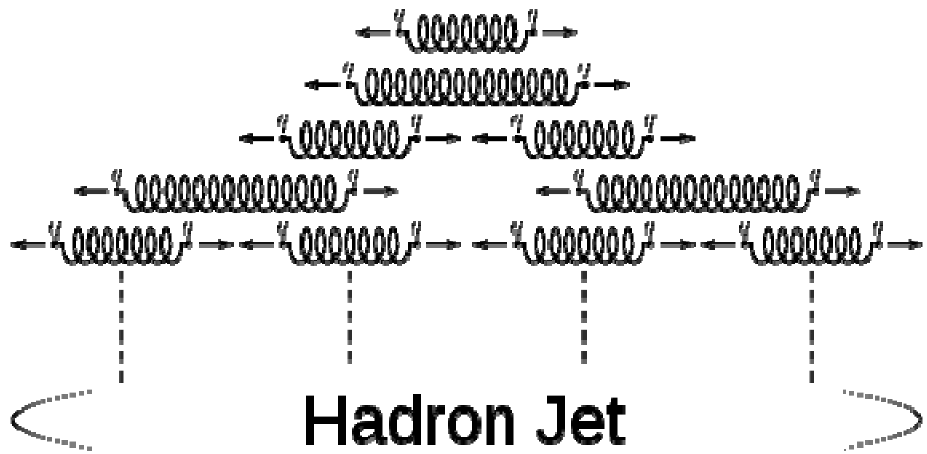
$$\lambda_7 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix} \quad \lambda_8 = \frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}.$$

Quark confinement

• quark potential

$$V_q(r) = (1+\gamma^0)a \log\left(\frac{r}{b}\right)$$





production of quark-antiquark pair cheaper!

• in nature, only white color existing, not isolated colors (red, blue, or green)

Debate of the century

the real particle should be able to travel in space as itself object.
so, the quark is never the real particle, it is just a part of the hadron,
that is, a parton!

the current level of theory cannot fully describe the strong interaction and the quark model.
along S-matrix theory, it is still open to the possibility of the non-localized quark.
it is a just mathematical limit,
so, quark indeed exist!

Three quarks for Muster Mark!
Sure he has not got much of a bark
And sure any he has it's all beside the mark.

-James Joyce, *Finnegans Wake*