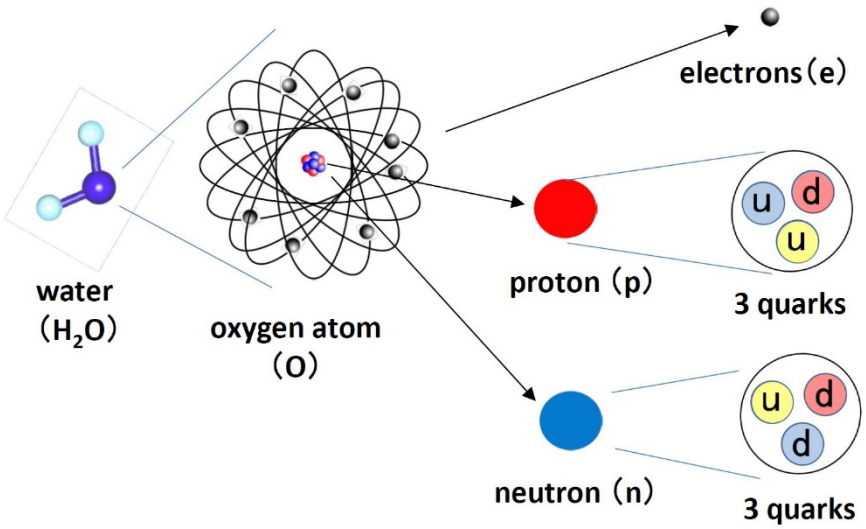
What the matters are made out of ?



http://atlas.kek.jp/public/HiggsCERNOpenDays_A4.pdf (or _each.pdf or _each.pptx)

proton

neutron

pion

Quarks are very strange !!

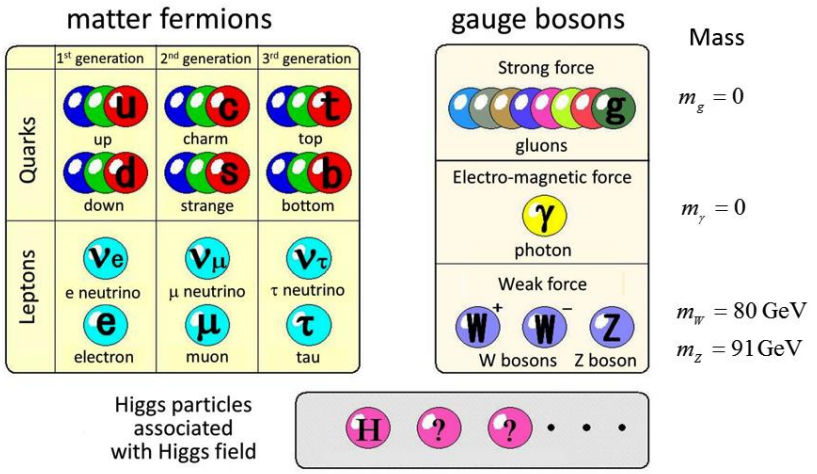
- Single quark never come out.
- They have fractional charges:
  - u up quarks $+\frac{2}{3}e$
  - d down quarks $-\frac{1}{3}e$
- Strong forces between quarks.

There are 4 forces in Nature

Strong	>	Electro-magnetic	>	Weak	>>>	Gravity
Bind quarks and making nucleus		Light, atom, crystal, radio, TV, phone, car, rain, thunder,.....		Sun/star energy, radio activities..		Falling apples, planet motions, satellite.....
Gluons		Photons		W, Z bosons		Gravitons

These forces are carried by

Elements of the Standard Model



2008

Y. Nambu

Introduced **Spontaneous Symmetry Breakdown (1959)**

2013

R. Brout & F. Englert , P. Higgs

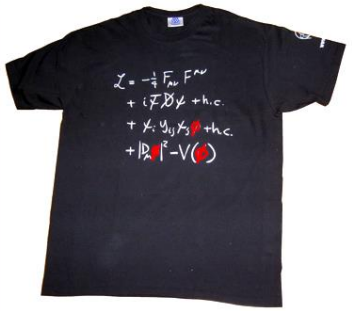
Found **BEH mechanism (1964)**

1979

S. Weinberg A. Salam

Proposed **Electro-weak theory (1967)**

CERN T-shirt



Standard Model

Higgs field ϕ must exist to generate particle masses.

QCD of strong interactions (1973)

Glashow-Weinberg-Salam Model

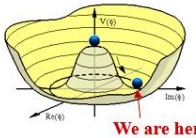
Φ=Higgs field free motion

Potential Energy by Higgs field

$$L = \bar{L} i\gamma^\mu D_\mu L + \bar{R} i\gamma^\mu D_\mu R - \frac{1}{4}\vec{W}^{\mu\nu}\cdot\vec{W}_{\mu\nu} - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} + \left|D_\mu\Phi\right|^2 - \left\{\mu^2\Phi^\dagger\Phi + \lambda\left(\Phi^\dagger\Phi\right)^2\right\} - G_e\left[\bar{R}\Phi^\dagger L + \bar{L}\Phi R\right]$$

where $D_\mu \equiv \partial_\mu + ig\vec{W}_\mu\cdot\frac{\vec{\tau}}{2} + ig'\frac{1}{2}B_\mu Y$, $B_{\mu\nu} \equiv \partial_\nu B_\mu - \partial_\mu B_\nu$, $L \equiv \begin{pmatrix}\nu_e \\ e^-\end{pmatrix}_L$, $R \equiv e_R^-$

Higgs-electron coupling



We are here

Symmetry Breakdown

$$SU(2)_L \times U(1)_Y \rightarrow U(1)_Q, \quad \Phi(x) = \frac{1}{\sqrt{2}}\begin{pmatrix}0 \\ \upsilon + h(x)\end{pmatrix}$$

$$L_\Phi = \frac{1}{2}(\partial h)^2 + \frac{1}{4}g_2^2 W^+W^-(\upsilon+h)^2 + \frac{1}{8}\frac{g_2^2}{\cos^2\theta_W}ZZ(\upsilon+h)^2 - \left[\frac{1}{2}(-2\mu^2)h^2 + \frac{1}{4}\mu^2\upsilon^2\left[-1 + \frac{4h^3}{\upsilon^3} + \frac{h^4}{\upsilon^4}\right] - \frac{G_e\upsilon}{\sqrt{2}}\bar{e}e - \frac{G_e}{\sqrt{2}}h\bar{e}e\right.$$

Therefore

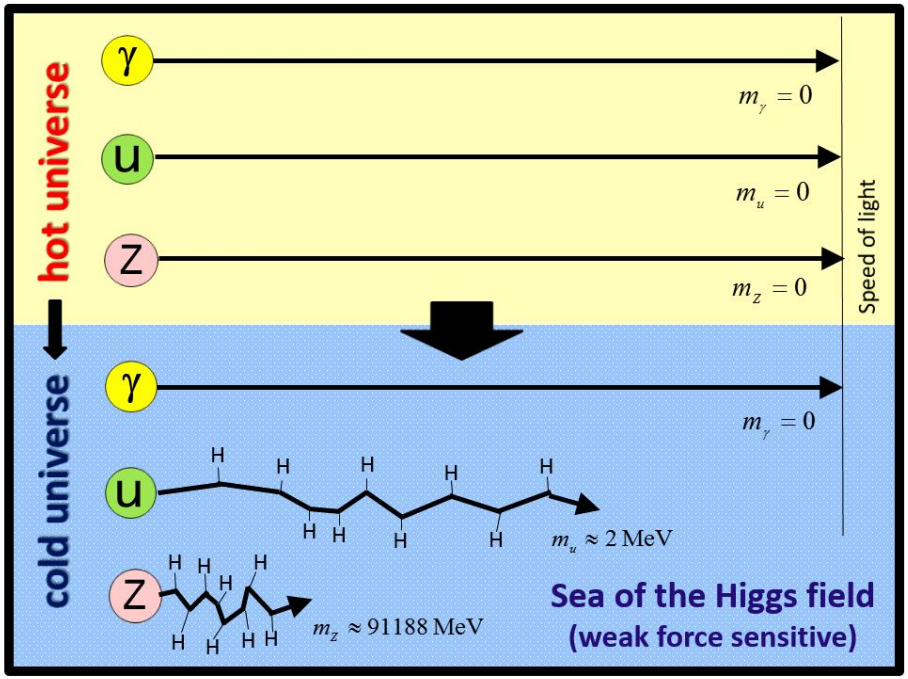
$$M_W = \frac{1}{2}g_2\upsilon, \quad M_Z = \frac{1}{2}\frac{g_2}{\cos\theta_W}\upsilon = \frac{M_W}{\cos\theta_W}, \quad M_H = \sqrt{-2\mu^2}, \quad M_e = \frac{G_e\upsilon}{\sqrt{2}}, \quad \upsilon = \frac{1}{\sqrt{\sqrt{2}G_F}} = 246\ \text{GeV}$$

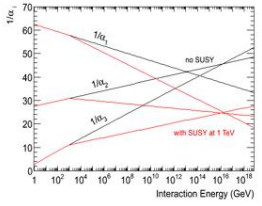
h= wave function of Higgs particle

Mass of Higgs

Mass of electron

Vacuum expectation value





SUSY particles may exist ?

SUSY = symmetry between Bosons and Fermions.
Spins of SUSY particles differ 1/2 from those of SM.

If SUSY particles exist at ~1 TeV, then

a. **3 forces can unify at high energy.**

b. **It avoids quantum divergence of Higgs particle mass.**

c. **Some SUSY particles can be dark matters.**