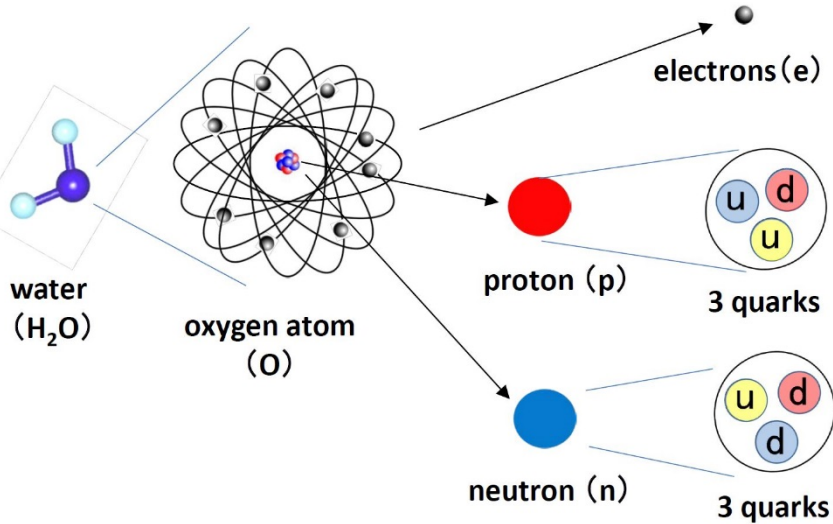
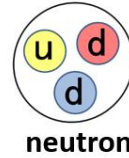
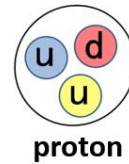


# What the matters are made out of ?



[http://atlas.kek.jp/public/HiggsCERNOpenDays\\_A4.pdf](http://atlas.kek.jp/public/HiggsCERNOpenDays_A4.pdf) (or \_each.pdf or \_each.pptx)

# 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





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




These forces are carried by

# Elements of the Standard Model

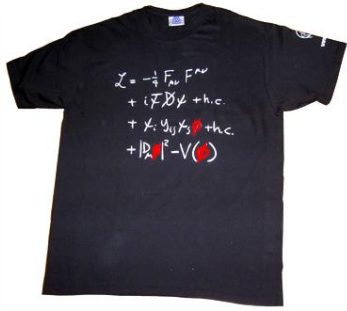
	1 <sup>st</sup> generation	2 <sup>nd</sup> generation	3 <sup>rd</sup> generation		Mass
Quarks	up down	charm strange	top bottom	Strong force gluons	$m_g = 0$
	Leptons	e neutrino electron	mu neutrino muon		tau neutrino tau
			Weak force W bosons Z boson	$m_W = 80 \text{ GeV}$ $m_Z = 91 \text{ GeV}$	
Higgs particles associated with Higgs field					

**Introduced Spontaneous Symmetry Breakdown (1959)**  
 2008   **Y. Nambu**

**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  $\phi$  must exist to generate particle masses.**

**QCD of strong interactions (1973)**

**Glashow-Weinberg-Salam Model**

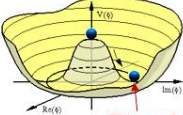
$\Phi = \text{Higgs field free motion}$       Potential Energy by Higgs field

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

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

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

**Higgs-electron coupling**



**We are here**

$$L_e = \frac{1}{2} (\partial h)^2 + \frac{1}{4} g^2 W^+ W^- (v+h)^2 + \frac{1}{8} \frac{g^2}{\cos^2 \theta_W} Z Z (v+h)^2 - \frac{1}{2} (-2\mu^2) h^2 + \frac{1}{4} \mu^2 v^2 \left[ -1 + \frac{4h^3}{v^3} + \frac{h^4}{v^2} \right] - \frac{G_e v}{\sqrt{2}} \bar{e} e - \frac{G_e}{\sqrt{2}} h \bar{e} e$$

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

**h = wave function of Higgs particle**      **Mass of Higgs**      **Mass of electron**      **Vacuum expectation value**

**hot universe**  $\downarrow$

$\gamma$   $m_\gamma = 0$

$u$   $m_u = 0$

$Z$   $m_Z = 0$

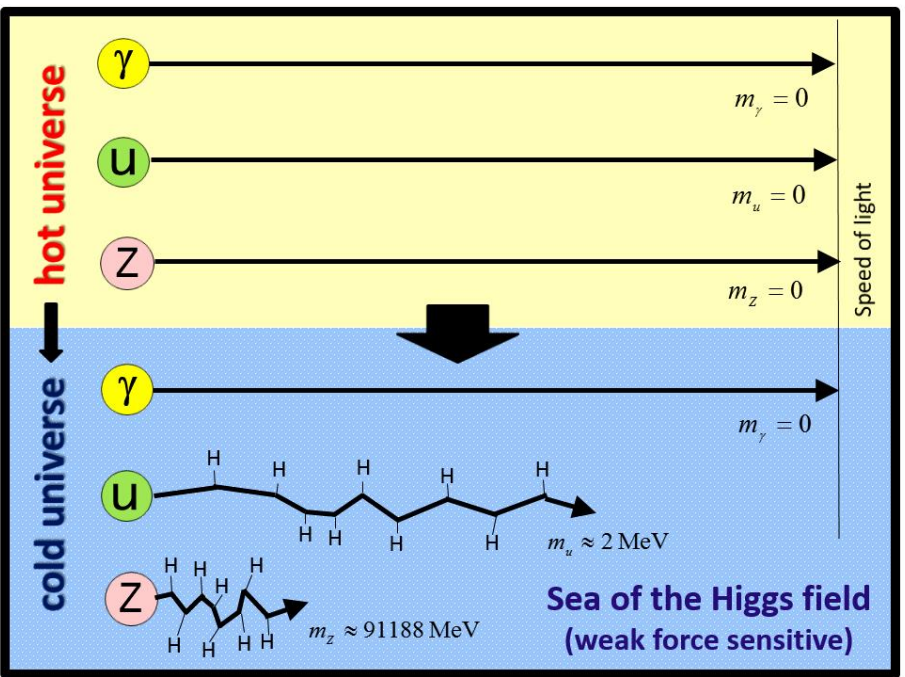
**cold universe**  $\downarrow$

$\gamma$   $m_\gamma = 0$

$u$   $m_u \approx 2 \text{ MeV}$

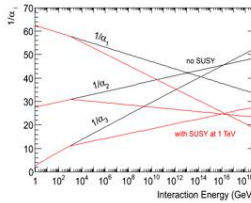
$Z$   $m_Z \approx 91188 \text{ MeV}$

**Sea of the Higgs field (weak force sensitive)**



**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**

- 3 forces can unify at high energy.
- It avoids quantum divergence of Higgs particle mass.
- Some SUSY particles can be **dark matters**.

**Standard Model**

$u_L$	$c_L$	$t_L$	$g$	$\bar{u}_L$	$\bar{c}_L$	$\bar{t}_L$	$\gamma$	$\bar{u}_R$	$\bar{c}_R$	$\bar{t}_R$	$Z^0$	$\bar{u}_L$	$\bar{c}_L$	$\bar{t}_L$	$g$
$d_L$	$s_L$	$b_L$	$W^\pm$	$\bar{d}_L$	$\bar{s}_L$	$\bar{b}_L$	$W^\pm$	$\bar{d}_R$	$\bar{s}_R$	$\bar{b}_R$	$W^\pm$	$\bar{u}_R$	$\bar{c}_R$	$\bar{t}_R$	$g$
$\nu_e$	$\nu_\mu$	$\nu_\tau$	$H^0$	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$	$H^0$	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$	$H^0$	$\bar{u}_L$	$\bar{c}_L$	$\bar{t}_L$	$g$
$e_L$	$\mu_L$	$\tau_L$	$H^\pm$	$\bar{e}_L$	$\bar{\mu}_L$	$\bar{\tau}_L$	$A^0$	$\bar{e}_L$	$\bar{\mu}_L$	$\bar{\tau}_L$	$A^0$	$\bar{u}_R$	$\bar{c}_R$	$\bar{t}_R$	$g$
$e_R$	$\mu_R$	$\tau_R$	$H^\pm$	$\bar{e}_R$	$\bar{\mu}_R$	$\bar{\tau}_R$	$H^\pm$	$\bar{u}_R$	$\bar{c}_R$	$\bar{t}_R$	$H^\pm$	$\bar{u}_L$	$\bar{c}_L$	$\bar{t}_L$	$g$

**Super Symmetric Model**

$\delta(\text{spin}) = \pm 1/2$