

### What the matters are made out of ?

water (H<sub>2</sub>O) → oxygen atom (O) → proton (p) → 3 quarks (u, d, u)  
 neutron (n) → 3 quarks (u, d, d)

electrons (e)

### 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.

proton (u, d, u)  
 neutron (u, d, d)  
 pion (u, anti-u)

### 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.....
<b>Glueons</b>	<b>Photons</b>	<b>W, Z bosons</b>	<b>Gravitons</b>

These forces are carried by

### Elements of the Standard Model

matter fermions			gauge bosons		Mass
	1 <sup>st</sup> generation	2 <sup>nd</sup> generation	3 <sup>rd</sup> generation		
Quarks	u (up)	c (charm)	t (top)	Strong force (gluons)	$m_g = 0$
	d (down)	s (strange)	b (bottom)		Electro-magnetic force (photon)
Leptons	$\nu_e$ (e neutrino)	$\nu_\mu$ (mu neutrino)	$\nu_\tau$ (tau neutrino)		
	e (electron)	$\mu$ (muon)	$\tau$ (tau)		

Higgs particles associated with Higgs field:  $H, \dots$

1979: S. Weinberg, A. Salam Proposed **Electro-weak theory** (1967)

1964: R. Brout & F. Englert, P. Higgs Found **BEH mechanism** (1964)

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

**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

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

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

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

**We are here**

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

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** → **cold universe**

Speed of light

$m_\gamma = 0$   
 $m_u = 0$   
 $m_Z = 0$

$m_\gamma = 0$   
 $m_u \approx 2 \text{ MeV}$   
 $m_Z \approx 91188 \text{ MeV}$

**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  $\sim 1 \text{ TeV}$ , 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 vs Super-Symmetric Model

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