Where to go now ?

--After Newton, Einstein, Heisenberg ……--

Tsutomu Yanagida,   TDLI in Shanghai

---- TDLI Summer School 2020 ----

- I was localized in a Hotel near by Tokyo for about 5 months
- In the Hotel, there is a small space in the ground floor where we have books and we can read them
- I found a book for the history of Isaac Newton and got very interested in reading it, since Newton was localized in a small village during the pandemic of the pest for about 1.5 years
- I will now tell you what I learned from the book

- Isaac Newton was born in a small village, *Woolsthorpe in England in 1643 and dead in London in 1727*
- *His family was farmer, but he hated to work in the field and his mother sent him to school*
- In 1661, he entered in Trinity College (of Cambridge University), but he had to work as an assistant of the college for the exemption of tuition fees
- He was mostly interested in chemistry and pharmacy during this period

- In 1664, he got a scholarship and had more time to have lectures in the college
- He was very much interested in lectures of mathematics and started to learn deeply mathematics
- Around that period they had a pandemic of the pest and he went back to his small home village and stayed there for about 1.5 years (1665-1667)
- During his stay he had an idea of law of universal gravitational force (万有引力）、

“looking an apple falling down to the ground”

- Newton published "**Principia** " in 1687

- He wrote laws of movement;

The second law is ***F=ma***

Law of gravitational force ***F=GmM/r^2***

m and M are inertial masses, and they are not weights !!! He considered that the force acts between **all bodies** !!!

Why did Newton get such ideas ?

It was known that the force between the Sun and planets is propotional to ***1/r^2*** **in 1660….**

The environment was in place

- Kepler (1571-1630) found the Kepler laws for the planetary motion and he guessed that the laws can be explained by 1/r^2 force

ellipse/circular orbit

- Galileo Galilei (1564-1642) found the law of inertia and the law of falling bodies

He also considered that the movement occurs only by external forces and he knew that we need a larger force to move a heavier body, but he did not notice a clear difference between weights and inertial masses

- But, Galilei did not consider that stones fall down to the ground by forces, and consider that the stones have some internal energies to fall down

- Newton believed that all changes of motion are given by External Force

$$F=ma$$

- There must be a big influence from Robert Hooke (1635-1702)
- The Hooke's law of force in spring,

$$F=k\,(dX)$$

dX is the spring length from the stationary point

He considered that the spring motion occurs by this force ***F***

He was very much interested in the forces between Planets, too!

- Hooke considered that the forces must become smaller as the distance between Planets longer
- He also considered ***$F = k (1/r^2)$***
- *Hooke suggested Newton to separate the motion of Planets into the radial direction and its orthogonal direction*
- ***Newton succeeded to explain the orbit of* Halley's Comet *by solving his equation***

$$F = m(d^2x/dt^2) = k (1/r^2)$$

- When Isaac Newton was young, movements of planets are the most challenging and important problem
- He tried to solve the problem by using mathematics!
- This is the famous words by Galileo Galilei,

"Nauture is a book written in words of **mathematics**" → "**Principia** " by Newton

Young Newton concentrated in solving the most important problem at that time

What is the most important problem to solve, now ?

- *$F=ma$ ……… Newton (1687)*

- *$E=mc^2$ ……… Einstein (1905)*

- *They did not ask what is the mass*

  Now, a question is what is mass ?

  Heisenberg said E has uncertainty ……?

What is Mass ?

Yanagida (2020) in Shanghai

Charge Quantization ?

運動量の大きさ: $P=mV$

$E=(1/2)(P^2/m)$

さて、相対論に移行すると対応する関係式は（この節では再び $c=1$ とおく）

$$E=\sqrt{p^2+m^2}$$

c: 光の速さ=1の単位系

$m \gg p$;　$E= m + (1/2)(p^2/m) + \ldots\ldots$

静止エネルギー　（m）

運動エネルギー　（$(1/2)(p^2/m)$）

$V= P/E = P/(m + \ldots.) =P/m +\ldots\ldots$

さて、運動量*P*無限大の極限を考えてみよう

$E \rightarrow P \quad : \quad V=P/E \rightarrow 1$

光の運動と比べてみよう　光の質量はゼロである

$E=P \longrightarrow V=P/E=1=c$

正の質量(m>0)を持つ粒子の速さは光の速さを超えられない!!!

- The velocity v of a massive particle can not exceed the light velocity C

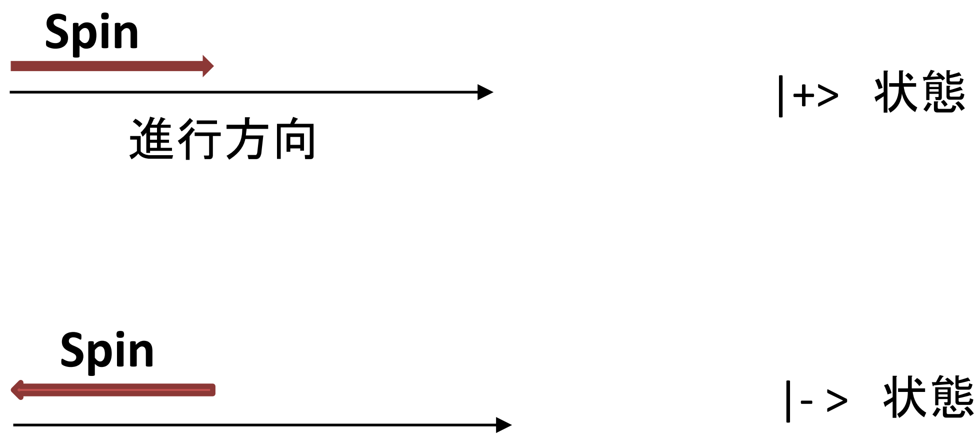
$$v < C$$

- Consider the mass of electron (電子）

- The electron is a fermion and has two states with different spins (1/2)
- They are a left-handed fermion |+> and right-handed fermion |->

The spin is a quantum number of a kind of rotation (angular momentum)

さて、電子(electron)を考えよう
電子はスピン(spin)***1/2***を持っていてフェルミオンと呼ばれている
このフェルミオンにはスピンの向きによって二つの状態がある



電子の質量はゼロではないので電子の走る速さは光より遅い

電子より早く走って電子を追い抜く人から|+>の状態を見てみよう

|-> の状態に見える

フェルミオンが質量を持つためには|+>の状態と|->状態の混合状態が必要である

If the electron has a mass, you can ride on a rocket which runs faster than the electron. The direction of the velocity become opposite and helicity is changed

- To give a mass to the electron, we need two states, left-handed and right-handed electron

- |massive electron> = |+> + |-> !!!

quantum mechanics

もし電子に質量がなければ、電子は光の速さで走る
この電子を追い抜くことはできない。

|+> ⟷ |-> 状態の混合は起きない

|+> と|->は独立な状態である

|+> を左巻き電子、 |-> を右巻き電子と呼びそれぞれを
e_L と e_R と書く

私たちは、この宇宙ができた当初は電子は質量を持っておらず
e_L とe_R は独立な粒子として振舞っていたと考えている

何故なの？

弱い相互作用 (Weak Interaction)

中性子のベーター崩壊

n → p + e + ν(ニュートリノ)

この崩壊で放出される電子**e**は左巻きの状態**e_L**のみである!!!

つまり弱い相互作用にかかわる電子は**e_L**のみで右巻きの状態の**e_R**はかかわってはならない
このような分離ができるのは電子の質量がゼロの時のみである

このような考えに基づき素粒子の標準理論が作られて、成功している

- The observed weak interactions show that the left-handed electron and the right-handed electron have different quantum numbers under the weak interactions

- |electron> = |+> + |-> ???

  It is forbidden by super selection rule

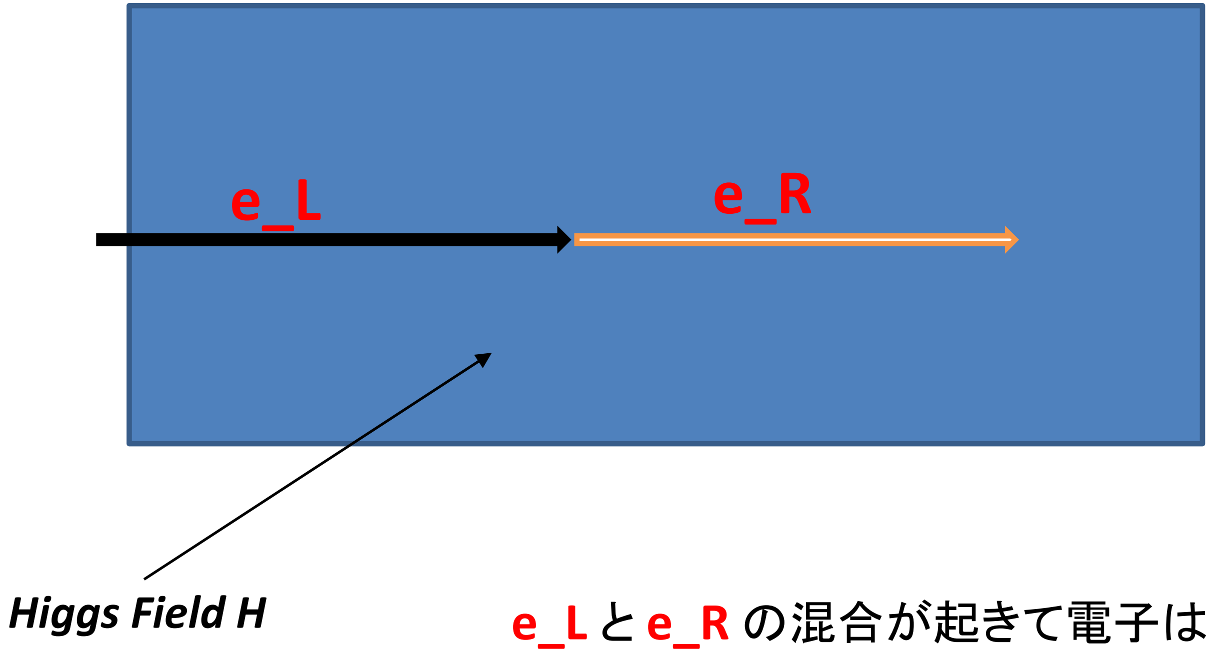
  The electron must be massless fermion

どうして電子は質量を持っているの？

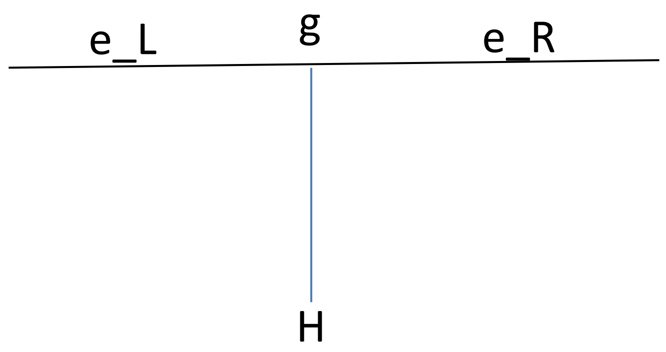
鍵を握るのはヒッグス粒子

Higgs Mechanism

宇宙の温度が冷えてくるとこの宇宙はヒッグス粒子で満たされ始める



e_L と **e_R** の混合が起きて電子は質量を持つ



$$m_e = g \, \langle H \rangle$$

$\langle H \rangle = 246$ GeV , $g = 5 \times 10^{-6}$ → $m_e = 0.5 \times 10^6$ eV

$E = mc^2 = m$ （$c=1$の単位系）

素粒子の質量をエネルギーの単位を用いて表す

- Lets consider the mass of the Higgs boson (spin=0) ;

M^2 H* H

There is no reason to forbid this mass!

Compare the electron mass m

me_R e_L

The left-handed electron e_L should be converted to the right-handed electron e_R if they have a mass

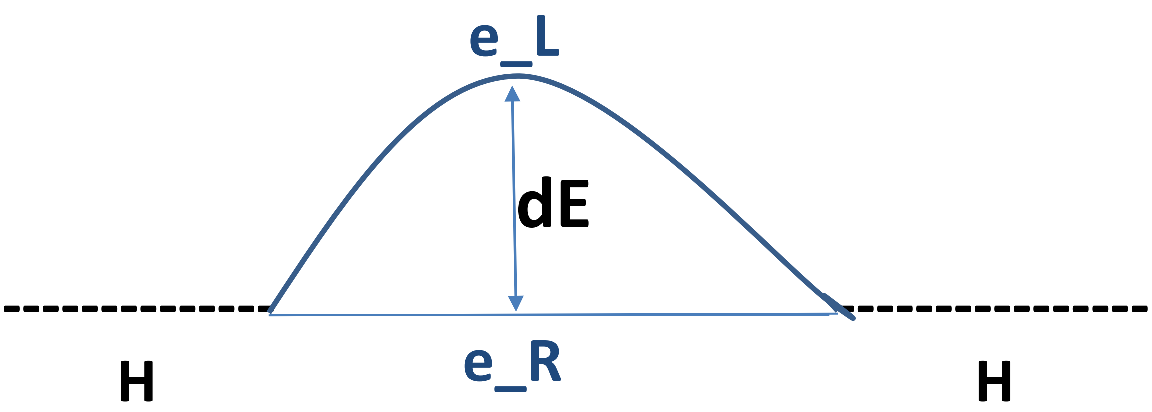
Thus, we can control the mass of the electron by a symmetry (Higgs controls it)

- The Higgs boson has a coupling

He_Re_L

Recall the Heisenberg uncertainty principle

dE x dt =h_bar



dt ~ 1/dE

The Higgs gets energy dE in the short time t~1/dE whose product is dEx(1/dE) ~ constant h_bar

But integrate it from dE=0 to dE= infinity

Then we get infinite energy !!!

Remember the Einstein formula

E=mc^2

Mass = Energy → The Higgs mass becomes

infinity !!!

But, the observed Higgs boson mass ~ 125 GeV

This is a big problem in the standard theory!!!

- **How do you solve this serious problem ?**

- You might doubt to integrate up to dE=infinity
- If we take dE<M~ a few 100 GeV, the Higgs gets a mass ~100 GeV, which is consistent with the observation

- But, the small neutrino masses indicate that M is very large as M=10^{15} GeV
- The neutrinos get also masses by quantum mechanical effects also which is
- **m(neutrino)~<H>^2/M** seesaw mechanism (~1979)

- Using <H>~100 GeV and m(neutrino) ~0.01 eV

We obtain M~10^{15} GeV !!!

What is the next solution?

A cancellation by introducing unknow particles ?

Sakata (~1950)

- A solution by **Supersymmetry** (超対称性）

- Boson ← → Fermion

- Since the mass of Fermion is controlled, the mass of Boson is also controlled

↓

Extension Of Space-Time

Bosonic variables b1 and b2,

b1xb2 = b2xb1

Fermionic variable f1 and f2

f1xf2 = -f2x f1

Supersymmetry is a unification of bi and fi

Space and time are bosonic coordinates

We need fermionic space coordinates

The space time = (x,y,z,t; f1,f2,f3,f4)

Charge Quantization

The electromagnetic charge of the electron is **-1**, while that of the proton is **+1**

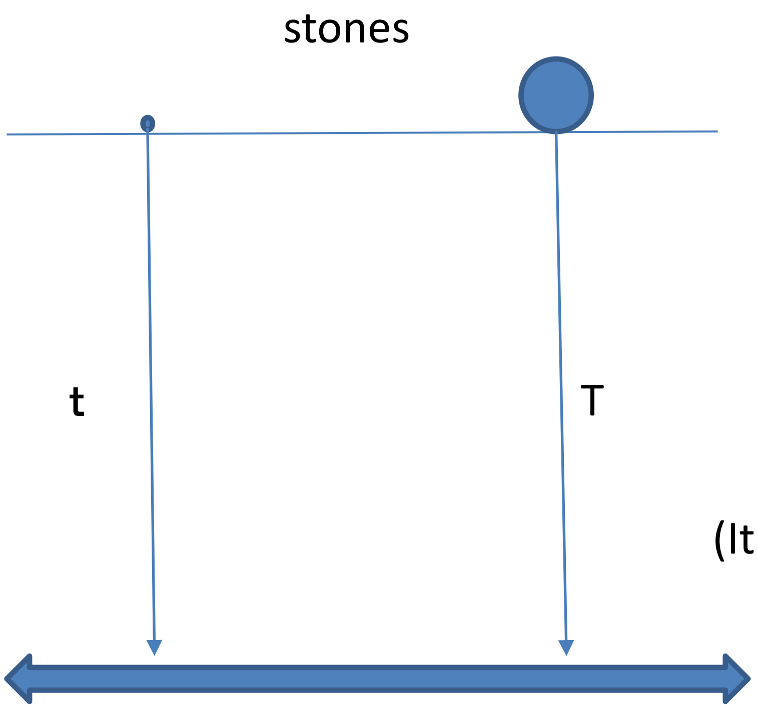
The electromagnetic charges of the neutrino and the neutron are both **0**

- ***Why So ?***

This is a fine tuning problem

- **We did not find a convincing solution**

- ***But, it is the historical fact that fine tuning problems gave us important clues to new physics !***



$t = T$

Galilei experiments

(It was known 1000 years before)

It is a fine tuning !　　**Why ?**

- I guess that people considered at that time that both stones came from the Earth and they are sons or daughters of the Earth
- They want to come back to their mother Earth and this is the reason why two stones fell down to the ground, but the moon not
- The mother loves both of them equally and this is the reason why they fell down at the same time

- This explanation for the fine tuning may not be too bad
- Formulate it mathematically !
- How to formulate that the Earth, their mother, loves them equally ? The big stone is heavy and the small one is light
- Weight is Force F and hence F=Mg and mg'
- Equally means g=g'

- Now assume the Newton's second law $F=ma$, a is the acceleration
- Then, we get $F=Mg=Ma$ and $F=mg=ma'$
- M and m are cancelled and their motions are equally described by $a=g$ and $a'=g$
- They fell down to the ground at the same time
- **Newton solved the fine tuning problem, which led us a completely new world !!!**

- **New observations in experiments were most important for creating new Science always**

In particular, anomalies !

- Discoveries of small anomalies changed physics at that time and led us a new physics
- Before ~1600, people believed that planet's orbits are perfect circular, but some observer found **small deviations** from the perfect circular orbits
- Kepler proposed ellipse orbits and found a very consistent explanation of motions of all planets, assuming that the center is SUN
- We began to believe the **Copernican theory !**

- Now, we have recently found a very very tiny deviation from our belief, that is the **cosmological constant**
- Before the experimental discovery we believed that the cosmological constant is exactly zero
- Nobody found any explanation of this tiny cosmological constant
- This is a big question to the fundamental law

$$CC \sim 10^{-128} M^4_{PL}$$

- **Undiscovery was also important!**

- **Michelson- Morley experiment**; They could not confirm the presence of **Ether,** which every body believed at that time

- → **Einstein special relativity**

- There are many observations we could not solve in the present physics
- We don not know what is **the dark matter**, the dark energy, we did not confirm the origin of **very small neutrino masses**, the presence of **baryon asymmetry in our universe** and we do not know a correct solution to the strong CP problem, **the axion**..........

- If you want to be the next **Newton, Einstein, Heisenberg**,….., try to solve such fundamental problems

You are young

To be ambitious !!!

Thank you very much