

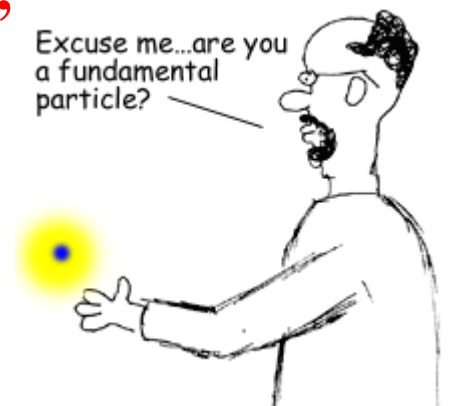
---

People have long asked,

“What is Fundamental ?”

“What is the world made of ?”

“What holds it together ?”



Elementary  
Particles

# Particle Discovery

New  
Particles

electron  
(Thomson) 1897

photon  
(Planck:  
blackbody radiation  
Einstein:  
photoelectric effect ) 1900  
1905

1911

proton  
(Rutherford)

1914

H-atom (Proton+Electron)  
(Bohr)

---

positron  
(Anderson)  
(Dirac 1928)

1931

1932

neutron  
(Chadwick)

muon  
(Anderson, Noddormeyer)

1937

$\oplus$   
Street, Stevenson)

Rabi asked:



---

1947

Charged pion ( $\pi^+$ )

(Powell)

predicted by Yukawa, 1935

$K^0$

(Rochester, Butler)

1949

$K^+$

(Powell)

1950

Neutral pion ( $\pi^0$ )

1953

Gell-mann  Nishijima :  
SU(3) flavors (introduce “strangeness” )

---

1955

antiproton

$\bar{\nu}_e$

1956

antineutron

(Cowan, Reines)

predicted by Pauli, 1933

1961

Gell-mann, Ne'eman :

Eightfold Way (baryon, meson)



predict  $\Omega^-$

$\bar{\nu}_\mu$

1962

(found in 1964)

(Lederman, Schwartz, Steinberger)

---

1964

$u d s \bar{u} \bar{d} \bar{s}$   
(confinement)

$\Delta^{++}$  (u u u)

$\Delta^{-}$  (d d d)

$\Omega^{-}$  (s s s)

Quarks Model  Gell-mann, Zweig  
baryon: (qqq), meson: (q $\bar{q}$ )

Greenberg, Nambu :  
3-flavors, 3-colors

---

1970

Glashow, Iliopoulos, Mainai : (GIM)  
propose charm quark

$c$

(Ting, Richer)

( long lifetime  $\sim 10^{-20}$  sec,  
instead of  $10^{-23}$  sec )

1974

November  
Revolution

$J/\Psi ( c \bar{c} )$

(Ting, Richer)

$\tau$

(Perl)

1975

$\Lambda_c^+ ( u d c )$

$\Sigma_c^{++} ( u u c )$

---

gluon

1976

$D^0 (c \bar{u})$

$D^+ (c \bar{d})$

DIS data :  $\int F_2^{\nu N}(\bar{x}) dx \approx 0.5$

→ existence of gluon

DESY(PETRA): confirm in  
 $e^+ e^- \rightarrow 3 \text{ jets}$

b

(Lederman)

1977

$D_s (c \bar{s})$

$\Upsilon (b \bar{b})$

$W^-$  Jan. 1983

$Z^0$  June

$B^0 (b \bar{d})$

$B^- (b \bar{u})$

(Rubbia, van der Meer) CERN

( Electroweak theory of  
Weinberg, Glashow, Salam,  
1967 )

$t$

1995

Fermilab

$\nu_\tau$

2000

$H$  (??)

20??

$H$ ??

B-mesons  
B-baryons

---

# Theory

1950's QED

Feynman, Schwinger, Tomonaga

- ◆ Lamb shift :  $2S_{1/2} - 2P_{1/2}$  (H-atom)
- ◆  $\alpha_{em}$  : lifetime of positronium ( $e^- e^+$ )
- ◆  $(g - 2)$  of  $e^-$  :  $\Delta(g - 2) \sim 10^{-11}$

- 
- 1954 Yang-Mills Non-abelian Gauge Theory  
(Yang, Mills)
  - 1956 Parity violation  
(Lee, Yang)
  - 1963 Higgs Mechanism  
(Higgs, Nambu, Goldstone )
  - 1967 Electroweak Theory  
(Glashow, Weinberg, Salam )

---

1970's Quantum Chromodynamics (QCD)

1972 Renormalizability  
(‘t Hooft, Veltman)

1973 Asymptotic Freedom  
(Gross, Wilczek, Politzer)

1974 Standard Model of Particle Physics  
  
Grand Unified Theory (GUT)  
(Glashow, Georgi)

---

1970 ~ SUSY, String, Extra Dimension,...

Brief History of SUSY

String Theory

1968: Veneziano  
Model

1973: Fermionic  
String

1973/4:  
Gravity in String  
Theory

1973/4 SUSY Lagrangian  
(Volkov, Akulov, Wess, Zumino)

1976 Supergravity, Superstring

1981~ SUSY GUT

1984 Anomaly Cancellation in Superstring

# Unexpected New Phenomenology

~~CP~~

1964  $K^0 - \bar{K}^0$

1990's  $B^0 - \bar{B}^0$

Leptons??

$\nu$  oscillation

1970's ~ 1990's

$$\nu_\epsilon - \nu_\mu$$

$$\nu_\mu - \nu_\tau$$

$$\nu_\epsilon - \nu_\tau \quad (??)$$

$$M_\nu \neq 0$$

Top physics (??)

Higgs physics (??)

- \* Cabibbo (1963)
  - \* GIM (1970)
  - \* Kobayashi-Maskawa (1973)
- (before the discovery of C)

# References

<http://particleadventure.org/>

<http://www.universeadventure.org/>

<http://www.cpepweb.org/>

<http://web.ihep.su/owa/dbserv/hw.part1>