Standard Model

A Brief Description by

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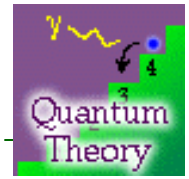
History of Particle Physics

Earliest times - 1550 AD: The Ancients

1550 - 1900 AD: The Scientific Revolution and Classical Mechanics



1900 - 1964 AD: Quantum Theory

1964 - Present: The Modern View (the Standard Model)

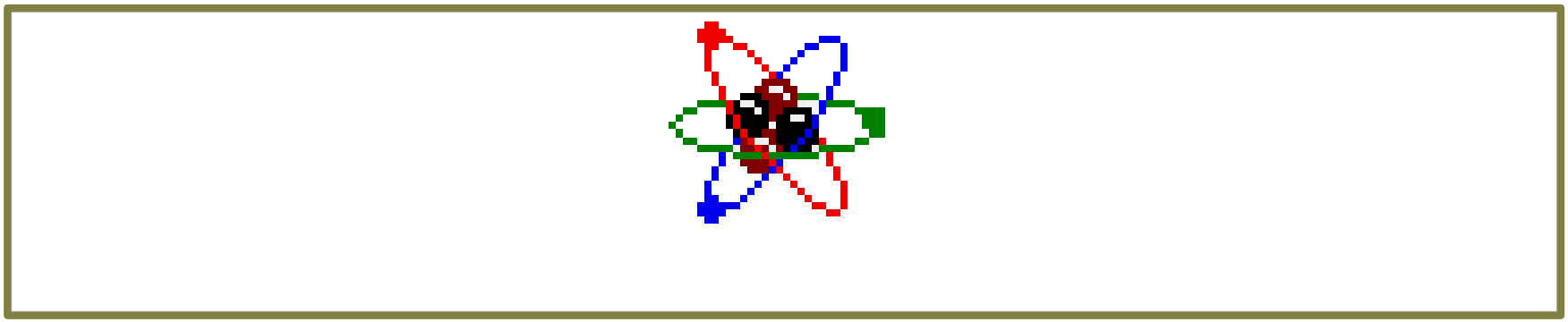
Introduction

- Standard Model – a framework to explain elementary particles.
  - Electromagnetism
  - Weak interaction
  - Strong interaction
- SM does not include gravity.
- Biggest success of Standard model – unification of weak and electromagnetism.

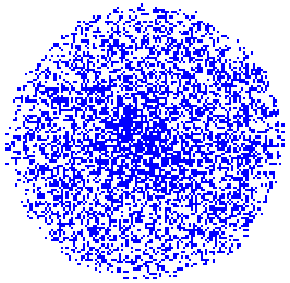
Particle Physics Prior to Accelerator

- Discovery of electron
- Rutherford scattering experiments led to discovery of nucleus and proton
- Planetary model of atom
- Quantum Mechanics and development of Charge cloud mode of atom

Planetary model of atom



The Cloud Charge Model



Motivation for the invention of Accelerator

- Questions already answered
  - Atomic spectra and orbits of electrons
  - Nuclear isotopes
- Questions pending
  - What is the force behind radioactive decay that produce alpha particles, beta particles and gamma rays?
  - Why protons in the nucleus do not burst out because of electromagnetic repulsion?

Enter the Accelerator

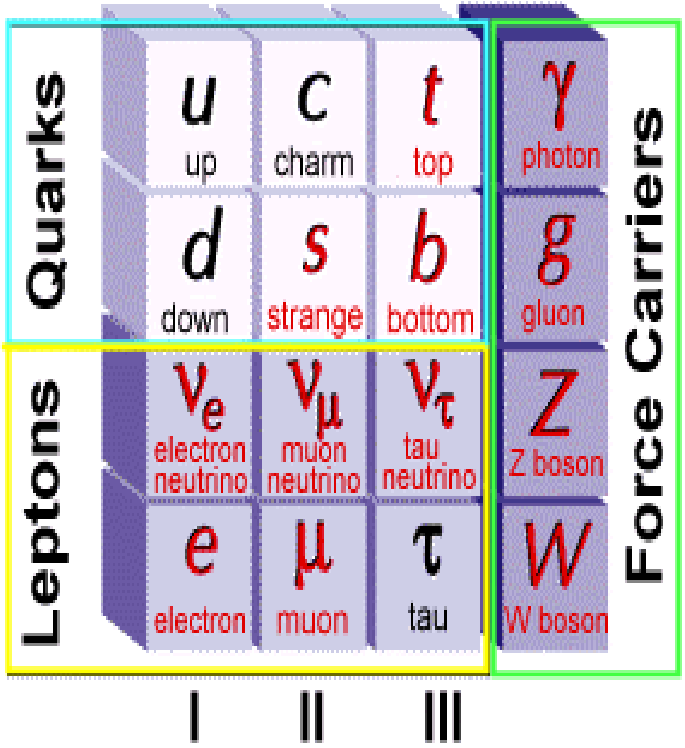
- Role of Accelerator in the development of Standard Model
  - High speed particles
  - Small wavelength associated with particles
- Particle Zoo
  - More than 100 new particles were discovered

Accelerator

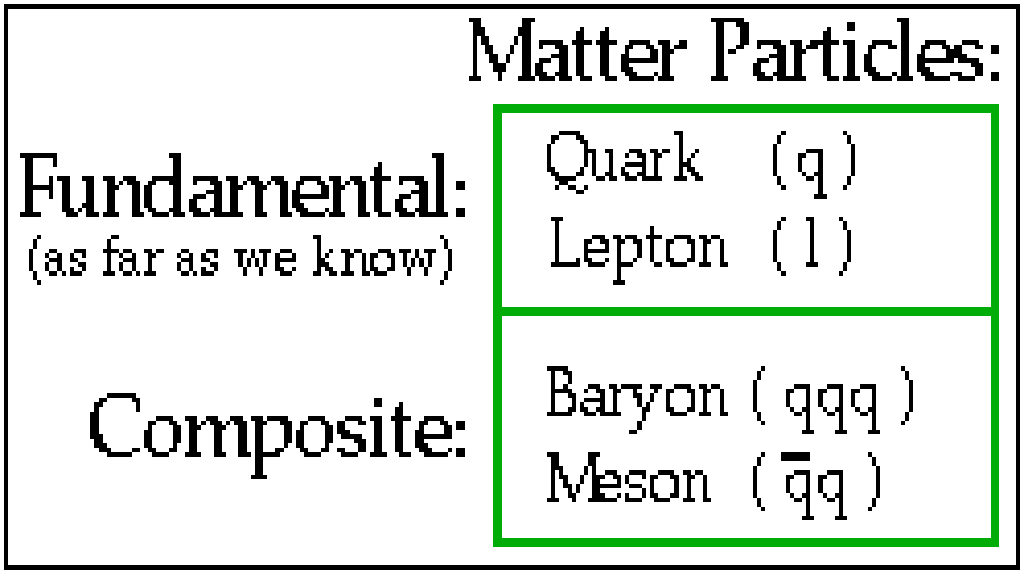
Introduction to Quarks

- The Quark Proposal
  - Gellmann and Zweig
  - Quarks and antiquarks
  - Fractional charges
  - Quarks can not be seen individually
  - Experimental evidence for the presence of quarks

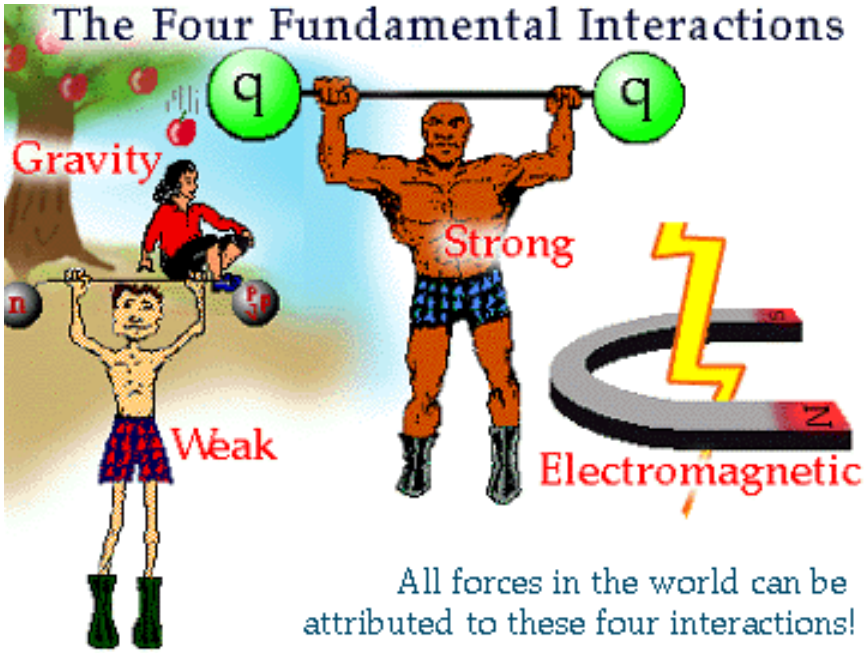
Elementary Particles



Fundamental matter particles according to SM



- Baryons are made of three quarks and have half integral spin of h bar.
- Mesons are made of quark and antiquark and have 0,1,2, .. spin of h bar.


The Four Fundamental Interactions
q
q
Gravity
Strong
n
p
Weak
Electromagnetic
All forces in the world can be
attributed to these four interactions!

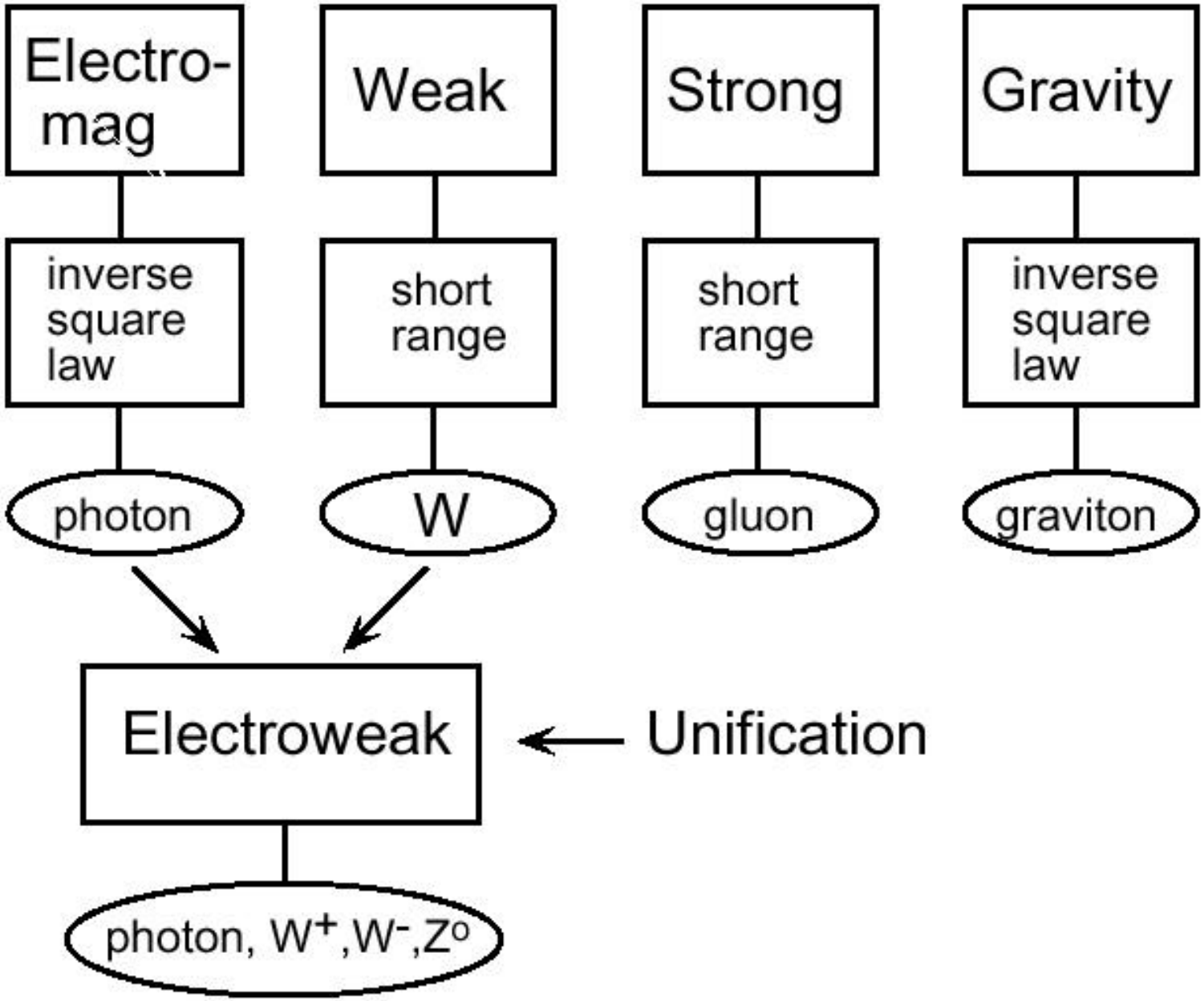
Unseen Effect

Fundamental Interactions

- Electromagnetism
  - Force carrier of Electromagnetism
  - Role of Electromagnetism in the formation of atom
  - Why atoms combine to form molecules when atom itself is a neutral entity?
- Weak Interaction
  - Role of weak interaction in the decay of higher mass particles
  - Range of weak interaction
- Strong Interaction
  - Role of strong interaction in the formation of hadrons
  - Color and strong interaction
  - Range of strong interaction
  - Why nucleons join to form nucleus when a nucleon is colorless?

Unification of Weak Interaction and Electromagnetism

- Weinberg, Salam, and Glashow
- Force carrier particles – W, Z and photons
- Masses of force carrier particles and symmetry breaking.
- Temperature range where weak and EM are one force.


Electro-
mag
Weak
Strong
Gravity
inverse
square
law
short
range
short
range
inverse
square
law
photon
W
gluon
graviton
Electroweak
Unification
photon, W+,W-,Zo

Timeline of the Universe - Standard Model

Time since 0	Event	Description	Temperature
15 x 10^{9} yrs	Now	Galaxies, stars, planets, and us	3 K
10^{9} yrs ?	Galaxy formation	bulges and halos of normal galaxies form	20 K
10^{6} yrs	Microwave Background	recombination - transparent to photons	3000 K
3 min	Nucleosynthesis	light elements formed	10^{9} K
6 sec	Electron-Positron pairs	creation of electrons	6 x 10^{9} K
2 sec	Neutrinos decouple	creation of neutrino background	10^{10} K
2 x 10^{-6} sec	Proton-Antiproton pairs	creation of nucleons	10^{13} K
2 x 10^{-10} sec	**Electroweak unification**	**E-M and weak force same**	**10^{15} K**
10^{-35} sec ?	Inflation	universe exponentially expands by 10^{26}	10^{27} K
10^{-35} sec	Grand Unification	E-M/Weak and Strong forces same	10^{27} K
10^{-44} sec	Quantum Gravity	Unification of all 4 forces	10^{32} K
< 10^{-44} sec	Planck Era	No concept of space or time?	> 10^{32} K

Questions remaining for Standard Model

- Three family of quarks
- Why the need for two other family when we see only the fist family in nature?
- Dominance of matter over antimatter
- Dark Matter
- Dark Energy
- Higgs Boson and distribution of mass to particles
- How to incorporate quantum version of gravity in SM?

Beyond Standard Model

- Supersymmetry and shadow particles
- Grand Unification of interactions

Conclusion

- The success of Standard Model to explain observed phenomena
- Verification of the subtle predictions of Standard Model by experiments
- Particles predicted by Standard Model have been observed except Higgs Boson.
- Dependence of Standard Model on Higgs Boson
- Supersymmetry – an extension of Standard Model but none of the particles predicted by SUSY has been detected.