The Standard Model: A Theory of Everything

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Abstract:
The standard model (SM) in the context of local gauge symmetry $SU(2) \times U(1) \times SU(3)_C$ emerged as precise and accurate theory.[3] Particle physics aims to understand the nature of matter, space-time in their most fundamental manner. Quarks, leptons and hadrons along with mediators makes unified non-collapsing symmetry of strong and electromagnetic interactions in quantum chromodynamics (QCD) and quantum electrodynamic (QED). The higher mass scale in gravitational interactions is unknown physics beyond standard model (BSM). As symmetry breaking in weak interactions leads to productive tactics to unfold matter-antimatter asymmetry provided by Higgs mechanism in the era of high energy physics (HEP).

Keywords: *The standard model, high energy physics*

1. Introduction

Primarily atoms were indestructible and considered as basic building block of matter. Cathode ray experiment, carried out by J. J. Thomson, introduced the new era in the exploration of universe by the discovery of electron. The gold foil experiment yielded a proton and latter detection of chargeless particle, neutron along with electron emerged as a complete structure of atom. In early 20th century, nucleons and electron could be regarded as constituent particles. The four fundamental interactions involving fermions and bosons results to have extension of SM.

In the present review we discuss basic elements of SM. Particles are classified into three-fold generation by mediators with addition of colour flavour to each family of quarks. The screening of quark composition and conserving nature carried out to some extent to check loop holes in SM.

2. Classification of Particles

2.1 Fermions and Bosons

Particle classification in SM is twofold: fermions and bosons.[1] They are very fundamental in nature to date. Fermions are referred as matter particles as they make up most of physical matter[1] in our universe. Six quarks and six leptons as a family member of fermions obey Fermi-Dirac statistics. The leptons with integral electric charge are spin ½ particles. An electron (e), muon (μ) and tauon (τ) have their respective neutral leptons, namely, electron-type neutrino (ν_e), muon-type neutrino (ν_μ), tau-type neutrino (ν_τ). The ratio of its electric charge (Q) to electron charge ($|e|$) of first family of leptons have -1.

The quarks with fractional charge of $+\frac{2}{3}|e|$ comprises up (u), charm (c), top (t) while $-\frac{1}{3}|e|$ charge is carried by down (d), strange (s), bottom (b) quarks. Leptons seems to exist as free particles whereas quarks do not. If we assign three different colours to each flavour of quark, it is noted that the total charge of all fermions is zero. The other types of particles, known as bosons, obey Bose-Einstein statistics. Bosons also called force carrier particles with integral spin.

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2.2 Antiparticle

An antiparticle has same mass and lifetime with opposite sign of charge, magnetic moment and helicity assigned to its particle. Feynman introduced graphical way for representation of interactions between particles and fields. The direction of antiparticle in Feynman diagram is showed by reverse arrow to the time scale in quantum electrodynamic (QED).[2]

2.3 Hadrons

Hadrons are categorised into mesons and baryons. Two types of quark combination are established in nature: (QQQ) = baryons and $(Q\bar{Q})$ = meson. Some Hadrons with their composition are given in Table. 1.1.

Table 1.1 Quark composition of some meson and baryon state

Meson	Composition	Baryon	Composition
π^+	$u\bar{d}$	p	uud
K^0	$d\bar{s}$	n	uud
π^0	$\frac{1}{\sqrt{2}}(d\bar{d}-u\bar{u})$	Λ^0	uds
η_0	$\frac{1}{\sqrt{2}}(d\bar{d}+u\bar{u}+s\bar{s})$	Ω^-	sss
ρ	$\frac{1}{\sqrt{2}}(u\bar{u}-d\bar{d})$	Ξ^0	uss

3. Interactions of Particles and Conservation Rules

Boson and fermion mediators are exchanged in four fundamental field, namely Strong, Electromagnetic, weak and strong interactions. The gluon (G), a massless particle, is accountable for binding of quarks in nucleons and proton and neutron in nuclei in strong interaction. Electromagnetic interactions are responsible for the virtually interchangeable photon (γ). Emission of electron and neutrino with $W^{\pm}$ and Z^0 mediating bosons are incorporated in the weak interactions. Though the macroscopic world is governed by a gravitational field, it is the weakest of all the fundamental interactions mediated by exchange of the gravitons (g) on the scale of experiments in HEP.

In analysing nuclear reaction, it is necessary to conserve charge, energy-momentum from classical approach. Additional conservation laws are electric charge (Q), baryon number (B), lepton number and strangeness (S), isospin (I). The composite formula for electric charge, isospin, strangeness and hypercharge can be written as follows:

$$\frac{Q}{|e|} = I_3 + \frac{Y}{2} \quad (1)$$

Where I_3 is the third component of isospin and the quantity $Y = B + S$ is called hypercharge.

4.Test for Field Conservation

In strong interactions, all quantum numbers are conserved and isospin $SU(3)$ colour symmetry is invariant. According to CPT theorem, under successive operations of C (charge conjugation), P (parity operation) and T(time reversal) taken in any order yield all interactions to be invariant, which is verified by the experiments. It was believed that weak interactions were violating the C and P separately. The CP violation in neutral kaon (K^0) decay leads to broken $SU(2) \times U(1)$ electroweak symmetry.[4] The observed matter-antimatter asymmetry of the universe is connected with spontaneous symmetry breaking by Higgs mechanism. The potential of scalar Higgs field ϕ would be

$$V = -\frac{1}{2}\mu^2\phi^2 - \frac{1}{4}\lambda\phi^4 \quad (2)$$

where λ is the dimensionless constant and μ is the mass of particle.

5. Limitations of SM

The SM provides compact description of fundamental constituents as well as of strong, weak and electromagnetic interactions. However, SM does have following limitations:

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1. Gravitational interactions are excluded as difficulties start to arise where quantum effect at Plank scale ($\sim 10^{19}\ GeV$) could be significant. This is regarded as hierarchy problem.
2. Neutrinos are assumed to be massless in SM but they are called Majorana particles with finite mass in solar and atmospheric experiments.
3. The SM contains some 17 arbitrary parameters which is also a questionable.
4. The matter-antimatter asymmetry is beyond physics of SM.

6. Conclusion

The SM is the most triumphant theory of particles and it lays out ingredients of six quarks, six leptons, four force-carrying particles ruled by strong, weak and electromagnetic forces. Violation of conservations principles in electroweak interaction yield new vacuum to propose new advance theory, supersymmetry (SUSY), grand unified theory (GUT) in contemporary particle physics.

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