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Review Article

Progressing Beyond the Standard Model

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The Standard Model has enjoyed considerable success in describing a whole range of phenomena in particle physics. However, the model is considered incomplete because it provides little understanding of other empirical observations such as, the existence of three generations of leptons and quarks, which apart from mass have similar properties. This paper examines in some detail the basic assumptions upon which the Standard Model is built and compares these with the assumptions of an alternative model, the Generation Model. The Generation Model provides agreement with the Standard Model for those phenomena which the Standard Model is able to describe, but it is shown that the assumptions inherent in the Generation Model allow progress beyond the Standard Model.

1. Introduction

The Standard Model (SM) of particle physics [1, 2] was developed throughout the 20th century, although the current formulation was essentially finalized in the mid-1970s following the experimental confirmation of the existence of quarks.

The SM has enjoyed considerable success in describing the interactions of leptons and the multitude of hadrons (baryons and mesons) with each other as well as the decay modes of the unstable leptons and hadrons. However, the model is considered to be incomplete in the sense that it provides little understanding of several empirical observations such as the existence of three families or generations of leptons and quarks, which apart from mass have similar properties; the mass hierarchy of the elementary particles, which form the basis of the SM; the nature of the gravitational interaction, and the origin of *CP* violation in the neutral kaon system.

The inability of the SM to provide an understanding of such important empirical observations has become very frustrating to particle physicists, especially the experimentalists, who find that all their other data are adequately described by the SM. In order to comprehend this dilemma and to progress beyond the SM, it is timely to reconsider the basic assumptions upon which the SM is built.

An excellent analogy of the SM situation [2] is the Ptolemaic model of the universe, based upon a stationary Earth at the center surrounded by a rotating system of crystal spheres refined by the addition of epicycles (small circular orbits) to describe the peculiar movements of the planets around the Earth. While the Ptolemaic model yielded an excellent description, it is a complicated diverse scheme for predicting the movements of the Sun, Moon, planets, and the stars around a stationary Earth and unfortunately provides no understanding of these complicated movements.

Progress in understanding the universe was only made when the Ptolemaic model was replaced by the Copernican-Keplerian model, in which the Earth moved like the other planets around the Sun, and Newton discovered his universal law of gravitation to describe the approximately elliptical planetary orbits. Indeed, it was only by removing the incorrect assumption that celestial bodies moved in "divine circles" that progress beyond the Ptolemaic model was achieved.

During the last decade, an alternative model to the SM, the Generation Model (GM), has been developed [2–5]. This model provides agreement with the SM for all the transition probabilities arising from every interaction involving any of the six leptons or the six quarks, which form the elementary particles of the SM. Moreover, the GM, which is based upon a much simpler and unified classification scheme of the leptons and quarks than that of the SM, provides some understanding of several phenomena, which the SM is unable to address. This represents progress beyond the SM, and in Section 2 the different assumptions inherent in the GM and in the SM will be closely examined. Section 3 indicates some of the progress beyond the SM achieved by the GM, and Section 4 states the conclusions.

2. Essential Differences between GM and SM

There are three essential differences between the GM and the SM: (a) the classification of the leptons and quarks in terms of additive quantum numbers, (b) the roles played by the mass eigenstate quarks and the weak eigenstate quarks, and (c) the nature of the weak interactions. Each of these essential differences will be examined in the following three subsections.

2.1. Classification of Leptons and Quarks. In the SM, the elementary particles that are the constituents of matter are assumed [2] to be the six leptons: electron neutrino (ν_e), electron (e^-), muon neutrino (ν_μ), muon (μ^-), tau neutrino (ν_τ), tau (τ^-), and the six quarks: up (u), down (d), charmed (c), strange (s), top (t), bottom (b), together with their antiparticles. These twelve particles are all spin-(1/2) particles and fall naturally into three families or generations: (i) ν_e, e^-, u, d; (ii) ν_μ, μ^-, c, s; (iii) ν_τ, τ^-, t, b. Each generation consists of two leptons with charges $Q = 0$ and $Q = -1$ and two quarks with charges $Q = +(2/3)$ and $Q = -(1/3)$. The masses of the particles increase significantly with each generation with the possible exception of the neutrinos, whose very small masses have yet to be determined.

In the SM, the leptons and quarks are allotted several additive quantum numbers. Table 1 shows the additive quantum numbers allotted to the leptons: charge Q, lepton number L, muon lepton number L_μ, and tau lepton number L_τ. Table 2 shows the additive quantum numbers allotted to the quarks: charge Q, baryon number A, strangeness S, charm C, bottomness, B and topness T. For each particle additive quantum number N, the corresponding antiparticle has the additive quantum number $-N$.

Tables 1 and 2 demonstrate that, except for charge, leptons and quarks are allotted different kinds of additive quantum numbers so that this classification of the elementary particles of the SM is *nonunified*.

The additive quantum numbers Q and A are assumed to be conserved in strong, electromagnetic, and weak interactions. The lepton numbers L, L_μ, and L_τ are not involved in strong interactions but are strictly conserved in both electromagnetic and weak interactions. The remaining ones, S, C, B, and T, are strictly conserved only in strong and electromagnetic interactions but can undergo a change of one unit in weak interactions.

The introduction of the above additive quantum numbers to both leptons and quarks took place over a considerable period of the 20th century in order to account for the observed interactions of the leptons and the multitude of hadrons (baryons and mesons) as well as the decay modes of the unstable leptons and hadrons.

Table 1: SM additive quantum numbers for leptons.

Particle	Q	L	L_μ	L_τ
ν_e	0	1	0	0
e^-	−1	1	0	0
ν_μ	0	1	1	0
μ^-	−1	1	1	0
ν_τ	0	1	0	1
τ^-	−1	1	0	1

Table 2: SM additive quantum numbers for quarks.

Particle	Q	A	S	C	B	T
u	+2/3	1/3	0	0	0	0
d	−1/3	1/3	0	0	0	0
c	+2/3	1/3	0	1	0	0
s	−1/3	1/3	−1	0	0	0
t	+2/3	1/3	0	0	0	1
b	−1/3	1/3	0	0	−1	0

The additive quantum numbers allotted to leptons (Table 1) were chosen by assuming symmetry arguments and the concept of weak isospin [4]. The introduction of lepton numbers, which were strictly conserved in both electromagnetic and weak interactions, provided a very useful description of the allowed decay modes and the possible reactions involving leptons.

Similarly, in general, the additive quantum numbers allotted to quarks (Table 2) were chosen by assuming symmetry arguments and the concept of strong isospin [4]. This concept of strong isospin, introduced by Heisenberg in 1932 [6], arose from the empirical fact that the neutron and proton appeared to be subject to the same nuclear force. The concept proved to be very useful for understanding phenomenologically the strongly interacting processes involving nucleons, pions and antinucleons. Strong isospin, like ordinary spin, was based mathematically upon an SU(2) symmetry.

Later in 1953, the strangeness quantum number was introduced to resolve the paradox of the copious associated production of strange particles and their individual very slow decay modes. Although strangeness was assumed to be conserved in strong interactions so that the strange particles were produced in pairs, strangeness was required to change by one unit as the individual strange particles slowly decayed. The nonconservation of strangeness by one unit in weak interaction processes suggested that this additive quantum number arose from some approximate, rather than an exact symmetry, in nature.

As more particles were discovered, the remaining additive quantum numbers, C, B, and T, were allotted to the additional quarks required to describe the new hadrons. These new additive quantum numbers were similar to strangeness in that they were not conserved in weak interaction processes. In hindsight, these "partially conserved" additive quantum numbers should have raised some doubts about the validity of the SM, especially since the corresponding quantum numbers allotted to leptons are conserved in all interactions.

Table 3: GM additive quantum numbers for leptons and quarks.

Particle	Q	p	g	Particle	Q	p	g
ν_e	0	−1	0	u	+2/3	1/3	0
e^-	−1	−1	0	d	−1/3	1/3	0
ν_μ	0	−1	±1	c	+2/3	1/3	±1
μ^-	−1	−1	±1	s	−1/3	1/3	±1
ν_τ	0	−1	0, ±2	t	+2/3	1/3	0, ±2
τ^-	−1	−1	0, ±2	b	−1/3	1/3	0, ±2

An important property of the weak interactions discovered in the late 1940s was their "universality". Analysis of experiments revealed that the coupling constants for muon decay and muon capture were of the same order of magnitude as those for β-decay. This led to the hypothesis of a *universal weak interaction* [7–12]. In the standard V-A theory [13, 14], it was assumed that the weak interactions were mediated by massive charged bosons, W^+ and W^-, and these weak interactions were referred to as "charge-changing" (CC) weak interactions. The occurrence of doublets such as (ν_e, e^-) and (ν_μ, μ^-) with separate lepton numbers and behaving similarly with respect to the "universal" CC weak interaction led to the notion of weak isospin, which like strong isospin was based mathematically upon an SU(2) symmetry.

To summarize, the SM classification of leptons and quarks in terms of the additive quantum numbers displayed in Tables 1 and 2 indicates both a *nonunified* (different quantum numbers for leptons and quarks) and a *complicated* scheme (four and six quantum numbers for leptons and quarks, resp.) of additive quantum numbers, some of which are *not conserved* in weak interaction processes. It seems that no attempt was made to unify the two different classifications of quarks and leptons, probably because the two systems were based largely upon the concepts of strong isospin and weak isospin, respectively. The above diverse complicated scheme of additive quantum numbers employed by the SM to classify its elementary particles forms one of the major stumbling blocks preventing progress beyond the SM [2]. Moreover, this basic problem inherent in the SM is exacerbated by the occurrence of several nonconserved additive quantum numbers and also by the fact that the SM fails to provide any physical basis for the classification scheme.

In the GM, all the above problems are overcome by the adoption of a *unified* classification of leptons and quarks [2]. Table 3 displays a set of only three additive quantum numbers: charge (Q), particle number (p), and generation quantum number (g) for the unified classification of the leptons and quarks corresponding to the current GM [15]. As for Tables 1 and 2 the corresponding antiparticles have the opposite sign for each particle additive quantum number.

Another feature of the GM classification scheme is that all three additive quantum numbers Q, p, and g are required to be conserved in all leptonic and hadronic processes. In particular, the generation quantum number g is conserved in weak interactions unlike some of the quantum numbers, for example, strangeness S, of the SM. This latter requirement led to a new treatment of quark mixing in hadronic processes [2, 3, 5], which will be discussed in Section 2.2.

Comparison of Tables 1 and 2 with Table 3 indicates that the two models, SM and GM, have only one additive quantum number in common, namely, electric charge Q, which serves the same role in both models and is conserved. The second additive quantum number of the GM, particle number p, replaces both lepton number L and baryon number A of the SM. The third additive quantum number of the GM, generation quantum number g, effectively replaces the remaining additive quantum numbers of the SM, L_μ, L_τ, S, C, B, and T.

The development of the GM classification scheme (Table 3), which provides a unified description of leptons and quarks, indicated that leptons and quarks are intimately related and led to the development of composite versions of the GM [2, 15, 16]. Table 3 shows that each generation of leptons and quarks has the same set of values for the additive quantum numbers Q and p. The generations are differentiated by the generation quantum number g, which in general can have multiple values. The latter possibilities arise from the composite nature of the leptons and quarks in what we have called the Composite Generation Model (CGM) [2].

It should be noted that the development of a composite GM is not possible in terms of the nonunified classification scheme of the SM, involving different additive quantum numbers for leptons than for quarks and the nonconservation of some additive quantum numbers, such as strangeness, in the case of quarks.

Composite versions of the GM have been developed during the last decade [2, 15, 16]. In the CGM, elementary particles of the SM are assumed to have a substructure consisting of massless "rishons" bound together by strong color interactions, mediated by massless hypergluons. Each rishon carries a color charge, red, green, or blue (cf quark in SM). This model is very similar to the SM in which hadrons have a substructure consisting of quarks bound together by strong color interactions, mediated by massless gluons.

The starting point for the development of the CGM was the very similar schematic models of Harari [17] and Shupe [18], which essentially described the charge states of the first generation of leptons and quarks in terms of two kinds of rishons: a T-rishon with $Q = +(1/3)$ and a V-rishon with $Q = 0$, as well as their antiparticles: $\overline{T}$ with $Q = -(1/3)$ and $\overline{V}$ with $Q = 0$. Harari [17] introduced the term "rishon" corresponding to the Hebrew word for "primary".

The CGM represents a major extension of the Harari-Shupe model with the introduction of a third kind of rishon, the U-rishon also with $Q = 0$. Table 4 gives the three additive quantum numbers of the GM allotted to the three kinds of rishons of the CGM. It should be noted that for each rishon additive quantum number N, the corresponding antirishon has the additive quantum number $-N$.

It is assumed that each kind of rishon carries a color charge, red, green, or blue, while their antiparticles carry an anticolor charge, antired, antigreen, or antiblue. The CGM postulates a strong color-type interaction corresponding to a local gauge $SU(3)_C$ symmetry (analogous to quantum chromodynamics (QCD) [19]) and mediated by massless hypergluons, which is responsible for binding rishons and antirishons together to form colorless leptons and colored quarks.

Table 4: CGM additive quantum numbers for rishons.

Rishon	Q	p	g
T	+1/3	+1/3	0
V	0	+1/3	0
U	0	+1/3	−1

Table 5: CGM of first generation of leptons and quarks.

Particle	Structure	Q	p	g
e^+	TTT	+1	+1	0
u	$TT\overline{V}$	+2/3	+1/3	0
$\overline{d}$	$T\overline{V}\,\overline{V}$	+1/3	−1/3	0
ν_e	$\overline{V}\,\overline{V}\,\overline{V}$	0	−1	0
$\overline{\nu}_e$	VVV	0	+1	0
d	$\overline{T}VV$	−1/3	+1/3	0
$\overline{u}$	$\overline{T}\,\overline{T}V$	−2/3	−1/3	0
e^-	$\overline{T}\,\overline{T}\,\overline{T}$	−1	−1	0

In the CGM, each lepton of the first generation (Table 5) is assumed to be colorless, consisting of three rishons (or antirishons), each with a different color (or anticolor), analogous to the baryons (or antibaryons) of the SM. These leptons are built out of T-rishons and V-rishons or their antiparticles $\overline{T}$ and $\overline{V}$, all of which have generation quantum number $g = 0$.

In the CGM, it is assumed that each quark of the first generation is a composite of a colored rishon and a colorless rishon-antirishon pair, $(T\overline{V})$ or $(V\overline{T})$, so that the quarks carry a color charge. Similarly, the antiquarks are a composite of an anticolored antirishon and a colorless rishon-antirishon pair, so that the antiquarks carry an anticolor charge.

The rishon structures of the second generation particles are assumed to be the same as the corresponding particles of the first generation plus the addition of a colorless rishon-antirishon pair, Π, where

$$\Pi = \frac{\left[\left(\overline{U}V\right) + \left(\overline{V}U\right)\right]}{\sqrt{2}}, \tag{1}$$

which is a quantum mechanical mixture of $(\overline{U}V)$ and $(\overline{V}U)$, which have $Q = p = 0$ but $g = \pm 1$, respectively. In this way, the pattern for the first generation is repeated for the second generation. Equation (1) indicates that the generation quantum number g for each second generation particle has two possible values, ± 1, although, in any given transition, the generation quantum is required to be conserved.

Similarly, the rishon structures of the third generation particles are assumed to be the same as the corresponding particles of the first generation plus the addition of two Π rishon-antirishon pairs so that the pattern of the first and second generation is continued for the third generation. The structure

$$\Pi\Pi = \frac{\left[\left(\overline{U}V\right)\left(\overline{U}V\right)+\left(\overline{U}V\right)\left(\overline{V}U\right) + \left(\overline{V}U\right)\left(\overline{U}V\right) + \left(\overline{V}U\right)\left(\overline{V}U\right)\right]}{2} \tag{2}$$

indicates that the generation quantum number for each third generation particle has three possible values $g = 0, \pm 2$, although, in any given transition, the generation quantum number is required to be conserved.

The color structures of both second and third generation leptons and quarks have been chosen so that the CC weak interactions are universal. In each case, the additional colorless rishon-antirishon pairs, $(\overline{U}V)$ and/or $(\overline{V}U)$, essentially act as spectators during any weak interaction process.

In the CGM, the three independent additive quantum numbers, charge Q, particle number p, and generation quantum number g, which are conserved in all interactions, correspond to the conservation of each of the three kinds of rishons [16]. Thus, the conservation of g in weak interactions is a consequence of the conservation of the three kinds of rishons (T, V, and U), which also prohibits transitions between the third generation and the first generation via weak interactions even for $g = 0$ components of third generation particles.

To summarize, the GM provides both a *simpler* and *unified* classification scheme for leptons and quarks. Furthermore, all the three additive quantum numbers, Q, p, and g are *conserved* in all interactions; in fact, the conservation of these three additive quantum numbers corresponds to the conservation of each of the three kinds of rishons [2], which constitute the building blocks of the composite leptons and quarks of the CGM. This provides a physical basis for the classification scheme of the GM and overcomes the problems inherent in the classification scheme of the SM.

2.2. Roles Played by Mass Eigenstate and Weak Eigenstate Quarks. The GM is obtained from the SM essentially by interchanging the roles of the mass eigenstate quarks and the weak eigenstate quarks [2]. In the SM, the mass eigenstate quarks form the constituents of hadrons, while the weak eigenstate quarks form weak isospin doublets analogous to the mass eigenstate leptons of the same generation. In the GM, the mass eigenstate quarks of the same generation form weak isospin doublets analogous to the mass eigenstate leptons of the same generation, while the weak eigenstate quarks form the constituents of hadrons. These differences between the SM and the GM arise from the different assumptions adopted by the two models to accommodate the *universality* of the CC weak interactions mediated by the W^+ and W^- vector bosons.

In the SM, the observed universality of the CC weak interactions in the lepton sector is described by assuming that each mass eigenstate charged lepton forms a weak isospin doublet ($i = (1/2)$) with its respective neutrino, that is, (ν_e, e^-), (ν_μ, μ^-), (ν_τ, τ^-) with each doublet having the third component of weak isospin $i_3 = (+(1/2), -(1/2))$. In addition, each doublet is associated with a different lepton number so that there are no CC weak interaction transitions between generations. This means that ν_e, ν_μ, and ν_τ interact with e^-, μ^-, and τ^-, respectively, with the *full* strength of the CC weak interaction, but the three neutrinos do *not* interact at all with the other charged leptons belonging to a *different* generation.

Thus, for leptonic processes, the concept of a universal CC weak interaction allows one to write (for simplicity we restrict the discussion to the first two generations only)

$$a\left(\nu_e, e^-; W^-\right) = a\left(\nu_\mu, \mu^-; W^-\right) = g_w. \tag{3}$$

Here $a(\alpha, \beta; W^-)$ represents the CC weak interaction transition amplitude involving the fermions α and β and the W^- boson, and g_w is the universal CC weak interaction transition amplitude. Lepton number conservation gives

$$a\left(\nu_e, \mu^-; W^-\right) = a\left(\nu_\mu, e^-; W^-\right) = 0, \tag{4}$$

so that there are no CC weak interaction transitions between generations in agreement with experiment.

On the other hand, the universality of the CC weak interactions in the quark sector is treated differently in the SM. For simplicity, we again restrict the discussion to the first two generations of quarks although the extension of the discussion to all three generations involves no essential changes. In the SM, it is assumed that the up (u) and charmed (c) quarks form weak isospin doublets with the so-called down (d') and strange (s') weak eigenstate quarks, respectively. These weak eigenstate quarks are linear superpositions of the mass eigenstate down (d) and strange (s) quarks:

$$\begin{aligned} d' &= d\cos\theta_c + s\sin\theta_c, \\ s' &= -d\sin\theta_c + s\cos\theta_c, \end{aligned} \tag{5}$$

where θ_c is a mixing angle introduced by Cabibbo [20], in 1963, into the transition amplitudes prior to the development of the quark model, in 1964. The SM assumes that the u and c mass eigenstate quarks interact with the d' and s' weak eigenstate quarks, respectively, with the *full* strength of the CC weak interaction and that the u and c mass eigenstate quarks do *not* interact at all with the s' and d' weak eigenstate quarks, respectively.

In terms of transition amplitudes, (5) can be represented as

$$\begin{aligned} a\left(u, d'; W^-\right) &= a\left(u, d; W^-\right)\cos\theta_c \\ &\quad + a\left(u, s; W^-\right)\sin\theta_c = g_w, \\ a\left(c, s'; W^-\right) &= -a\left(c, d; W^-\right)\sin\theta_c \\ &\quad + a\left(c, s; W^-\right)\cos\theta_c = g_w. \end{aligned} \tag{6}$$

In addition one has the relations

$$\begin{aligned} a\left(u, s'; W^-\right) &= -a\left(u, d; W^-\right)\sin\theta_c \\ &\quad + a\left(u, s; W^-\right)\cos\theta_c = 0, \\ a\left(c, d'; W^-\right) &= a\left(c, d; W^-\right)\cos\theta_c \\ &\quad + a\left(c, s; W^-\right)\sin\theta_c = 0. \end{aligned} \tag{7}$$

Equations in (6) indicate that the d' and s' quarks interact with the u and c quarks, respectively, with the full strength g_w. These equations for quarks correspond to (3) for leptons. Similarly, equations in (7) for quarks correspond to (4) for leptons. However, there is a fundamental difference between (7) for quarks and (4) for leptons. The former equations do not yield zero amplitudes because there exists some quantum number, analogous to lepton number, which is required to be conserved. This lack of a selection rule indicates that the notion of weak isospin symmetry for the doublets (u, d') and (c, s') is dubious.

In hindsight, the above technique for accommodating the universality of the CC weak interactions in the quark sector arose from two assumptions: firstly, the introduction of the strangeness quantum number S by Gell-Mann [21] and by Nakano and Nishijima [22] to describe the *associated production* of strange particles via a strong interaction process, which conserved S and the subsequent *slow decay* of the individual strange particles via a weak interaction process, which did not conserve S. This property of the weak interaction process was dependent upon a second assumption: strange particles contained an attribute called "strangeness", which was not present in nonstrange particles. Thus strange particles such as the K mesons and the Λ hyperon contained strangeness but nonstrange particles such as the pions and the proton did not. When the quark model of hadrons was proposed in 1964 by Gell-Mann [23] and Zweig [24], the second assumption above was essential for consistency since only strange particles contained strange quarks.

Thus, to summarize, the significant dubious assumption involved in the SM's method of accommodating the universality of the CC weak interactions in the quark sector is that the u and c mass eigenstate quarks form weak isospin doublets with the weak eigenstate quarks, d' and s', respectively. Basically, unlike the lepton sector, the SM has no conserved quantum number to support this assumption: the relevant quantum number, strangeness, is not conserved in such weak interaction processes.

The GM overcomes the above problem inherent in the SM by postulating two different assumptions.

Firstly, the GM postulates that the mass eigenstate quarks of the same generation, that is, (u, d) and (c, s), form weak isospin doublets and couple with the full strength of the CC weak interaction, g_w, like the lepton doublet (ν_e, e^-). Unlike the SM, the GM requires that there is no coupling between mass eigenstate quarks from different generations. This latter requirement corresponds to the conservation of the generation quantum number in the CC weak interaction processes.

Secondly, the GM postulates that hadrons are composed of weak eigenstate quarks such as d' and s' given by (5) in the two-generation approximation, rather than the corresponding mass eigenstate quarks, d and s, as in the SM. Thus, in terms of transition amplitudes, the GM postulates that

$$a\left(u, d; W^-\right) = a\left(c, s; W^-\right) = g_w, \tag{8}$$

$$a\left(u, s; W^-\right) = a\left(c, d; W^-\right) = 0. \tag{9}$$

Equations (8) and (9) are the analogues of (3) and (4) for leptons. These transition amplitudes establish a close lepton-quark parallelism with respect to weak isospin symmetry.

The GM differs from the SM in that it treats quark mixing differently from the method introduced by Cabibbo [20] to describe the universality of the CC weak interactions. Essentially, in the GM, the quark mixing is placed in the quark states (wave functions) rather than in the CC weak interactions. This allows a unified and simpler classification of both leptons and quarks in terms of only three additive quantum numbers, Q, p and g, each of which is conserved in all interactions.

2.3. Nature of the Weak Interactions. The SM recognizes [2] four fundamental interactions in nature: strong, electromagnetic, weak, and gravity. Since gravity plays no role in particle physics because it is so much weaker than the other three fundamental interactions, the SM does not attempt to explain gravity. In the SM, the other three fundamental interactions are assumed to be associated with a local gauge field [19].

For consistency, one theoretical requirement of a local gauge field mediated by vector (spin-1) particles is that these "gauge bosons" should be *massless*. Indeed the electromagnetic interactions, mediated by *massless* neutral spin-1 photons between electrically charged particles, are described by a U(1) local gauge theory called quantum electrodynamics. In addition, the strong interactions, mediated by *massless* spin-1 gluons between quarks carrying a color charge, are described by an SU(3) local gauge theory called quantum chromodynamics. On the other hand, the weak interactions, mediated by *massive* spin-1 W and Z particles between all the elementary particles of the SM, are also assumed in the SM to be described by a local gauge theory. This leads to an inconsistency problem since *massive* spin-1 mediating particles violate the gauge invariance principle of a local gauge theory.

The charged nature of the weak interaction gauge bosons means that the symmetries of the weak and electromagnetic interactions become entwined. In the SM, it is assumed, following a proposal by Glashow [25] in 1961, that the weak interaction is associated with the electromagnetic interaction by extending the overall symmetry to an SU(2) × U(1) local gauge theory.

This "electroweak theory" was a major step towards understanding the so-called "electroweak connection": *the charge-preserving weak interaction is completely fixed by the electromagnetic interaction and the CC weak interaction* [26, 27]. In this sense, it should be noted that the electromagnetic interaction involving the neutral photons and the weak interactions involving the charged W bosons and the neutral Z bosons are related but are not strictly unified since the relationship involves two independent coupling constants, electric charge and weak charge.

For the extended symmetry, SU(2) × U(1), assumed in the SM for the electroweak theory, the inconsistency problem referred to above applies not only to the massive W and Z bosons but also to the masses of the leptons and quarks as well: the finite masses of the leptons and quarks cause the Lagrangian describing the system to violate the SU(2) gauge invariance as a consequence of the parity violation of the weak interactions [28–31].

In the SM, these inconsistency problems are all overcome by postulating the existence of a condensate, analogous to the condensate of Cooper pairs in the microscopic theory of superconductivity, called the Higgs field. This new field is assumed to be a ubiquitous energy field so that it exists throughout the entire universe. It is accompanied by a new fundamental particle called the Higgs boson, which continuously interacts with other elementary particles by transferring energy from the Higgs field so that these particles acquire mass. This process is called the Higgs mechanism [32, 33].

The boson mass problem was resolved by Weinberg [34] and Salam [35], who independently employed the idea of spontaneous symmetry breaking involving the Higgs mechanism. The fermion mass problem [36] was resolved by assuming that originally massless fermions interact with the Higgs field such that when the massless fermions propagate in a vacuum with a nonzero equilibrium value of the field, they develop mass. In both cases, the Higgs mechanism causes the extended symmetry of the electroweak theory to be broken so that overall consistency is restored.

A second theoretical requirement of a local gauge theory involving spin-1 mediating particles is that it should be "renormalizable", that is, that any infinities arising in any calculated quantities should be capable of being made finite by acceptable renormalization techniques. In 1971, 't Hooft showed [37] that the electroweak theory of Glashow, Weinberg and Salam was renormalizable and this self-consistency of the theory led to its general acceptance.

However, in spite of these successes, the electroweak theory still has several problems. Firstly, it requires the existence of a new massive spin-0 boson, the Higgs boson, which notwithstanding some recent tantalizing results from the LHC [38, 39], still remains to be unambiguously detected. Secondly, the fermion-Higgs coupling strength is dependent upon the mass of the fermion so that a new parameter is required for each fermion in the theory. In addition, the requirement of a Higgs field, which fills the whole of space, leads to a cosmological constant term in the General Theory of Relativity, which far exceeds that allowed by observations [40].

The electroweak theory of the SM also has a few unanswered questions concerning its structure: How does the symmetry breaking mechanism occur within the electroweak interaction? What is the principle which determines the large range of fermion masses exhibited by the leptons and quarks?

The GM adopts [27] the point of view that the weak interactions, associated with the weak isospin symmetry, are *not* fundamental interactions arising from an SU(2) local gauge theory as in the SM. Rather, the weak interactions are residual interactions of a strong color force, responsible for binding the constituents of the leptons and quarks together. This latter force is assumed to be a strong color force, analogous to the strong color force of the SM, which binds quarks together to form baryons or mesons, and is associated with a local SU(3) gauge field mediated by massless hypergluons.

Thus, in the GM, the weak interactions are assumed to be "effective" interactions; that is, they are approximate interactions that contain the appropriate degrees of freedom to describe the experimental data occurring at sufficiently low energies for which any substructure and its associated degrees of freedom may be ignored. In the GM [2], leptons, quarks, and the W and Z bosons are all considered to be composite particles, built out of rishons or antirishons, held together by the strong color force. The massive vector bosons, which mediate the effective weak interactions, are analogous to the massive mesons, which mediate the effective nuclear interactions between neutrons and protons.

The nonfundamental nature of the weak interactions in the GM means that the question of renormalizability does not arise. Thus, the mediating particles may be massive since this does not destroy any SU(2) local gauge invariance giving rise to a fundamental interaction. In the GM, the fundamental interaction is the strong color interaction, which in principle leads to a renormalizable theory for the electroweak interactions, provided the substructure of leptons, quarks, and the W and Z bosons is taken into account.

3. Beyond the SM

The GM represents progress beyond the SM, providing understanding of several empirical observations, which the SM is unable to address: (i) the existence of three generations of leptons and quarks, which apart from mass have similar properties; (ii) the mass hierarchy of the elementary particles, which form the basis of the SM; (iii) the nature of the gravitational interaction, and (iv) the origin of CP violation in the neutral kaon system. Each of these empirical observations will be discussed in the following four subsections.

3.1. Existence of Three Generations of Leptons and Quarks. Progress beyond the SM was largely achieved by the development of the much *simpler* and *unified* classification scheme of leptons and quarks of the GM in terms of only three strictly conserved additive quantum numbers, rather than the nine additive quantum numbers (some being only partially conserved) of the diverse classification scheme of the SM (see Section 2.1).

The unified classification scheme of the GM indicated that leptons and quarks are intimately related and led to the development of composite versions of the GM, which we refer to as the Composite Generation Model (CGM) [2, 15]. The SM is unable to provide any understanding of either the existence of the three generations of leptons and quarks or their mass hierarchy, whereas the CGM suggests that both the existence and mass hierarchy of these three generations arise from the substructures of the leptons and quarks [2, 15, 41].

In addition the CGM led to a new paradigm for the origin of *all* mass: the mass of a body arises from the energy content of its constituents, in agreement with Einstein's conclusion [42], so that there is no need for the existence of a Higgs field with its accompanying problems.

In the CGM, the elementary particles of the SM have a substructure, consisting of massless rishons and/or antirishons bound together by strong color interactions, mediated by massless neutral hypergluons. This model is very similar to that of the SM in which quarks and/or antiquarks are bound together by strong color interactions, mediated by massless neutral gluons, to form hadrons. Since the mass of a hadron arises mainly from the energy of its constituents, the CGM suggests [41] that the mass of a lepton, quark, or vector boson arises entirely from the energy stored in the motion of its constituent rishons and/or antirishons and the energy of the color hypergluon fields, E, according to $m = E/c^2$. A corollary of this idea is that *if a particle has mass, then it is composite*. Thus, unlike the SM, the GM provides a *unified* description of the origin of *all* mass.

3.2. Mass Hierarchy of Leptons and Quarks. The CGM suggests that the mass hierarchy of the three generations arises from the substructures of the leptons and quarks [2, 15, 41].

In the CGM, it is envisaged that the rishons and/or antirishons of each lepton or quark are very strongly localized, since to date there is no direct evidence for any substructure of these particles. Thus the constituents are expected to be distributed according to quantum mechanical wave functions for which the product wave function is significant for only an *extremely small* volume of space so that the corresponding color fields are *almost cancelled*. Thus the constituents of each lepton or quark are localized within a very small volume of space by strong color interactions, which we have called *intrafermion* color interactions, acting between the colored rishons and/or antirishons.

The mass of each lepton or quark corresponds to a characteristic energy primarily associated with these intrafermion color interactions. It is expected that the mass of a composite particle will be greater if the degree of localization of its constituents is smaller (i.e., the constituents that are on average more widely separated). This is a consequence of the nature of the strong color interactions, which are assumed to possess the property of "asymptotic freedom" [43, 44], whereby the color interactions become stronger for larger separations of the color charges. In addition, the electromagnetic interactions between any charged rishons or between any charged antirishons will also cause the degree of localization of the constituents to be smaller causing an increase in mass. Furthermore, it should be noted that the large variation (<3 eV to 175 GeV) [2] in the masses of the elementary particles of the SM indicates that the mass of a particle is extremely sensitive to the degree of localization of its constituents.

In the CGM [2], it is envisaged that each lepton of the first generation basically exists in an antisymmetric three-particle color state, which physically assumes a quantum mechanical *triangular* distribution of the three differently colored identical rishons (or antirishons), since the color interaction between each pair of rishons (or antirishons) is expected to be strongly attractive [19]. As indicated above, the charged leptons are predicted to have larger masses than the neutral leptons, since the electromagnetic interactions in the charged leptons will cause their constituent rishons (or antirishons) to be less localized than those constituting the uncharged leptons, leading to a substantially greater characteristic energy and a correspondingly greater mass.

Each lepton of the second and third generations is envisaged to be similar to the corresponding lepton of the first generation with one and two additional colorless rishon-antirishon pairs, respectively, being attached externally to the triangular distribution, leading quantum mechanically to a less localized distribution of the constituent rishons and antirishons so that the leptons of the second and third generations have increasing significantly larger masses than its corresponding first generation lepton.

In the CGM each quark of the first generation is a composite of a colored rishon and a colorless rishon-antirishon pair. This color charge structure of the quarks is expected to lead to a quantum mechanical *linear* distribution of the constituent rishons and antirishons, corresponding to a considerably larger mass than that of the leptons, since the constituents of the quarks are less localized as a consequence of the character (i.e., attractive or repulsive) of the color interactions [19].

Each quark of the second and third generations has a similar structure to that of the corresponding quark of the first generation, with one and two additional colorless rishon-antirishon pairs, respectively, being attached quantum mechanically so that the whole rishon structure is a longer linear distribution of the constituents. These structures are considerably less localized leading to increasing significantly larger masses than the corresponding first generation quark.

The $Q = +(2/3)$ quarks are expected to have considerably larger masses than the $Q = -(1/3)$ quarks of the same generation because of the electromagnetic repulsion of their two electrically charged constituent rishons. The top and charmed quarks certainly have considerably larger masses than the bottom and strange quarks, respectively. However, in the SM, the up quark ($Q = +(2/3)$) is required to have a smaller mass than the down quark ($Q = -(1/3)$); otherwise, the proton not the neutron would be unstable. In the GM, this anomaly is accounted for by the constituents of hadrons being weak eigenstate quarks rather than mass eigenstate quarks, as discussed in Section 2.2. The free proton not the free neutron is stable since the weak eigenstate quark d' has a larger mass than the u quark, containing about 5% of the strange quark mass.

To summarize, the mass hierarchy of the three generations of leptons and quarks is described by the degree of localization of their constituent rishons and/or antirishons. The degree of localization depends very sensitively upon both the color charge and the electric charge structures of the composite particle.

3.3. Nature of Gravitational Interaction. In the CGM, between any two leptons and/or quarks there exists a residual interaction arising from the color interactions acting between the constituents of one fermion and the constituents of the other fermion. We refer to these interactions as *interfermion* color interactions. Robson [41] proposed that such residual color interactions may be identified with the usual gravitational interaction. Based upon this earlier conjecture, Robson [2, 15] has presented a quantum theory of gravity, briefly described below, leading approximately to Newton's law of universal gravitation.

The mass of a body of ordinary matter is essentially the total mass of its constituent electrons, neutrons, and protons. In the CGM, each of these three particles is considered to be colorless. The electron is composed of three charged antirishons, each carrying a different anticolor charge, antired, antigreen, or antiblue. Both the neutron and the proton are composed of three quarks, each carrying a different color charge, red, green, or blue. All three particles are assumed to be essentially in a three-color antisymmetric state, so that their behavior with respect to the strong color interactions is expected basically to be the same. This similar behavior suggests that the interfermion interactions of the CGM between electrons, neutrons, and protons have several properties associated with the usual gravitational interaction [2, 15]: universality, infinite range, very weak strength, and attractive.

In the CGM, the above interfermion color interactions suggest a universal law of gravitation, which closely resembles Newton's original law that a body of mass m_1 attracts another body of mass m_2 by an interaction proportional to the product of the two masses and inversely proportional to the square of the distance (r) between the centers of mass of the two bodies:

$$F = \frac{H(r)\, m_1 m_2}{r^2}, \tag{10}$$

where Newton's gravitational constant G is replaced by a function of r, $H(r)$.

This difference arises from the self-interactions of the hypergluons mediating the interfermion color interactions [2, 15]. These self-interactions cause antiscreening effects [43, 44], which lead to an increase in the strength of the residual (interfermion) interaction acting between the two masses, so that G becomes an increasing function of r, $H(r)$.

This change in the gravitational interaction, especially for large separations of the interacting masses, has been shown [45] to be essentially equivalent to that of Milgrom's MOND theory [46]. This GM modification of Newton's law of gravity provides a physical understanding of the MOND theory, which accounts for the galaxy rotation problem [47] without the existence of dark matter haloes surrounding spiral galaxies.

3.4. CP Violation in the K^0–$\overline{K}^0$ System. As discussed in Section 2.2, the GM postulates that hadrons are composed of *weak eigenstate* quarks rather than mass eigenstate quarks as in the SM. One important consequence of this is that hadrons contain mixed-quark states, which may have mixed parity.

In the CGM, the constituents of quarks are rishons and antirishons. If one assumes the simple convention that all rishons have positive parity and all their antiparticles have negative parity, one finds that the down and strange quarks have opposite intrinsic parities, according to the proposed structures of these quarks in the CGM [2]: the d-quark consists of two rishons and one antirishon ($P_d = -1$), while the s-quark consists of three rishons and two antirishons ($P_s = +1$). The u-quark consists of two rishons and one antirishon so that $P_u = -1$, and the antiparticles of these three quarks have the corresponding opposite parities: $P_{\overline{d}} = +1$, $P_{\overline{s}} = -1$ and $P_{\overline{u}} = +1$.

In the SM, the intrinsic parity of the charged pions is assumed to be $P_\pi = -1$. This result was established by Chinowsky and Steinberger [48], using the capture of negatively charged pions in deuterium to form two neutrons, and led to the overthrow of the conservation of both parity (P) and charge-conjugation (C) [28–31], and later combined CP

conservation [49]. Recently, Robson [50] has demonstrated that this experiment is also compatible with the mixed-parity nature of the π^- predicted by the CGM: $\approx (0.95P_d + 0.05P_s)$, with $P_d = -1$ and $P_s = +1$. This implies that the original determination of the parity of the negatively charged pion is *not* conclusive, if the pion has a complex substructure as in the CGM.

Morrison and Robson [51] reexamined the *CP* violation observed by Christenson et al. [49] in terms of the mixed-quark states, involving mixed-parity states, of hadrons. This is briefly described below.

In the CGM, the K^0 and $\overline{K}^0$ mesons have the weak eigenstate quark structures $[d'\overline{s}']$ and $[s'\overline{d}']$, respectively. Neglecting the very small mixing components arising from the third generation, Morrison and Robson show that the long-lived neutral kaon, K_L^0, exists in a $CP = -1$ eigenstate as in the SM. On the other hand, the charged 2π system is as follows:

$$\begin{aligned} \pi^+\pi^- &= \left[u\overline{d}'\right]\left[d'\overline{u}\right] \\ &= \left[u\overline{d}\right][d\overline{u}]\cos^2\theta_c + [u\overline{s}][s\overline{u}]\sin^2\theta_c \\ &\quad + [u\overline{s}][d\overline{u}]\sin\theta_c\cos\theta_c \\ &\quad + \left[u\overline{d}\right][s\overline{u}]\sin\theta_c\cos\theta_c. \end{aligned} \tag{11}$$

For the above assumed parities of the quarks and antiquarks involved in (11), it is seen that the first two components are eigenstates of $CP = +1$, while the remaining two components $[u\overline{s}][d\overline{u}]$ and $[u\overline{d}][s\overline{u}]$, with amplitude $\sin\theta_c\cos\theta_c$, are not individual eigenstates of *CP*. However, taken together, the state $([u\overline{s}][d\overline{u}] + [u\overline{d}][s\overline{u}])$ is an eigenstate of *CP* with eigenvalue $CP = -1$. Taking the square of the product of the amplitudes of the two components comprising the $CP = -1$ eigenstate to be the "joint probability" of those two states existing together simultaneously, one can calculate that this probability is given by $(\sin\theta_c\cos\theta_c)^4 = 2.34 \times 10^{-3}$, using $\cos\theta_c = 0.9742$ [52]. Thus, the existence of a small component of the $\pi^+\pi^-$ system with eigenvalue $CP = -1$ indicates that the K_L^0 meson can decay to the charged 2π system *without* violating *CP* conservation. Moreover, the estimated decay rate is in good agreement with experimental data [52].

4. Conclusion and Discussion

Although the SM has enjoyed considerable success in describing the interactions of leptons and hadrons with each other as well as their decay modes, the model is considered to be incomplete in that it provides little understanding of several empirical observations such as the existence of three generations of leptons and quarks, which apart from mass have similar properties. Consequently, we have closely examined the basic assumptions upon which the SM is erected.

It has been found that the SM is founded upon three dubious assumptions, which present major stumbling blocks preventing progress beyond the SM. These are (i) the assumption of a diverse complicated scheme of additive quantum numbers to classify its elementary particles, (ii) the assumption of weak isospin doublets in the quark sector to accommodate the universality of the CC weak interactions and (iii) the assumption that the weak interactions are fundamental interactions described by a local gauge theory.

The SM diverse complicated classification scheme of leptons and quarks is nonunified in the sense that leptons and quarks are allotted different kinds of additive quantum numbers, preventing any possibility of developing a model describing any substructure of these particles. Although no such substructure has been detected to date, there are several empirical observations (e.g., the electron and the proton have exactly opposite electrical charges, the three generations of leptons and quarks, etc.), which suggest that both leptons and quarks probably do have a substructure. In addition, the SM fails to provide any physical basis for its adopted classification scheme.

The assumption of weak isospin doublets (u, d') and (c, s') in terms of the weak eigenstate quarks d' and s', given by (5), to accommodate the universality of the CC weak interactions is unsupported by the lack of a conserved quantum number: the relevant quantum number, strangeness, is not conserved in weak interactions.

The assumption that the weak interactions are fundamental interactions arising from a local gauge theory is at variance with the experimental facts: both the W and Z particles mediating the weak interactions are massive, and this conflicts with the requirement of a local gauge theory that the mediating particles should be massless in order to guarantee the gauge invariance. This problem has tentatively been overcome by the further assumption of the existence of a condensate, analogous to the condensate of Cooper pairs in the microscopic theory of superconductivity, called the Higgs field, which exists throughout the entire universe. This proposed field is accompanied by a proposed fundamental particle called the Higgs boson, which continuously interacts with the elementary leptons, quarks, and vector bosons by transferring energy from the Higgs field so that these particles acquire mass.

However, the resultant electroweak theory still has many problems and leaves several questions unanswered: How does the symmetry breaking mechanism occur within the electroweak theory? What is the principle which determines the large range of fermion masses exhibited by the leptons and quarks?

In the GM, the three dubious assumptions of the SM discussed above are replaced by three different and simpler assumptions. These are (i) the assumption of a simpler and unified classification of leptons and quarks; (ii) the assumption that the mass eigenstate quarks form weak isospin doublets and that hadrons are composed of weak eigenstate quarks; and (iii) the assumption that the weak interactions are not fundamental interactions.

In the GM, both the leptons and quarks are classified in terms of only three additive quantum numbers: charge (Q), particle number (p), and generation quantum number (g) so that the classification is unified. Furthermore, all these three additive quantum numbers are conserved in all interactions, corresponding to the conservation of each of the three kinds of rishons, which constitute the building blocks of the composite leptons and quarks of the CGM, thereby providing a physical basis for the three additive quantum numbers.

The GM treats quark mixing differently from the method introduced by Cabibbo and employed in the SM. The GM postulates that the mass eigenstate quarks form weak isospin doublets and couple with the full strength of the CC weak interaction, while hadrons are composed of weak eigenstate quarks such as d' and s', rather than the corresponding mass eigenstate quarks as in the SM. Thus the GM is obtained from the SM essentially by interchanging the roles of the mass eigenstate quarks and the weak eigenstate quarks. This permits a simpler unified classification of both leptons and quarks in terms of three strictly conserved additive quantum numbers.

The GM assumes that the weak interactions are not fundamental interactions arising from a local gauge theory but rather are residual interactions of the strong color interactions, responsible for binding the constituents of the leptons and quarks together. Thus, in the GM, the weak interactions are assumed to be "effective" interactions and the massive vector bosons, which mediate the effective weak interactions, are analogous to the massive mesons, which mediate effective nuclear interactions between nucleons.

The three alternative assumptions of the GM, discussed above, allow progress beyond the SM.

Firstly, the unified classification scheme of the GM led to the development of composite versions of the GM; that is, the elementary particles of the SM have a substructure, consisting of massless rishons and/or antirishons bound together by strong color interactions, mediated by massless neutral hypergluons. Since the mass of a hadron arises mainly from the energy of its constituents, the CGM suggested that the mass of a lepton, quark, or vector boson arises entirely from the energy stored in the motion of its constituent rishons and/or antirishons and the energy of the color hypergluon fields. In addition it indicated that if a particle has mass, then it is composite. Thus, unlike the SM, the GM provides a unified description of *all* mass.

Secondly, the CGM suggested that the large variation (<3 eV to 175 GeV) in the masses of the leptons and quarks may be described by the degree of localization of their constituent rishons and/or antirishons, the degree of localization depending very sensitively upon both the color charge, and the electric charge structure of the composite particle. In addition, the CGM predicts that the $Q = +(2/3)$ quarks should have considerably larger masses than the $Q = -(1/3)$ quarks of the same generation. This is certainly true for the second and third generations of quarks: the top quark and charmed quark have considerably larger masses than the bottom quark and strange quark, respectively. In the SM, the first generation of quarks seems to present an anomaly in that the proton consists of two up quarks and one down quark, while the neutron consists of two down quarks and one up quark so that the proton is only stable if the down ($Q = -(1/3)$) quark is more massive than the up ($Q = +(2/3)$) quark. In the GM, this anomaly is accounted for by the constituents of hadrons being weak eigenstate quarks rather than mass eigenstate quarks. The free proton, not the free neutron, is stable since the weak eigenstate quark d' has a larger mass than the u quark, containing about 5% of the strange quark mass.

Thirdly, the similar behavior of the interfermion color interactions of the CGM between electrons, neutrons, and protons, the constituents of ordinary matter, suggests that these residual color interactions may be identified with the usual gravitational interaction. Indeed, in the CGM, the interfermion color interactions suggest a universal law of gravitation, which is very similar to Newton's original law but with one significant difference: the usual constant of gravitation G is no longer a constant but is an increasing function of the distance, r, separating the two interacting masses. This is a consequence of the nature of the interfermion color interactions and leads to changes in the gravitational interaction, especially at large separations of interacting masses. This modification of Newton's law of gravitation has been shown to account for the galaxy rotation problem [47] and also implies that something is missing in the General Theory of Relativity in the weak classical limit [53]. Indeed the relation between the nature of gravity within the framework of the CGM and that of the General Theory of Relativity needs further study.

Fourthly, the GM assumes that hadrons are composed of weak eigenstate quarks, that is, mixed-quark states. This gives rise to several important consequences, which differ from the predictions of the SM: (i) the CGM predicts [5] that the proton contains ≈1.7% of strange quarks, while the SM predicts ≪1.7% and (ii) the CGM predicts [54] a scalar contribution to the neutral pion decay amplitude of ≈2.5%, while the SM predicts 0%. In both cases the experimental data [55–57] are unable to distinguish between the predictions of the two models.

In addition, the mixed-quark states can have mixed parity. For the CGM, it is found that the d-quark and the s-quark have opposite intrinsic parities so that the weak eigenstate d'-quark and the weak eigenstate s' quark have mixed parity. This has been shown to lead to the existence of a small component of the $\pi^+\pi^-$ system with eigenvalue $CP = -1$ so that the K_L^0 meson, which is essentially in a $CP = -1$ eigenstate, can decay to the charged 2π system without violating CP conservation. Moreover, the estimated decay rate is in good agreement with experiment.

Apparent CP violation has been observed in systems other than the neutral kaon system [58]. These rather more complicated systems should be investigated within the framework of the CGM to see if CP is also conserved in these cases.

Thus, it is timely to embrace the GM as a refinement of the SM and to employ both the GM and the CGM to further progress beyond the SM.

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