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The Invisible Color: A Doorway to Particle Masses?

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Abstract

Without modifying the Standard Model Lagrangian, a representation of the flavors of elementary fermions (quarks and leptons) is introduced in terms of a triplet of internal colors, each associated with a triplet of three-valued indices. These colors are closely related to the color understood in the chromodynamic sense, and this connection is made explicit. Based on this representation, approximate quantitative constraints on the masses of elementary fermions and the gauge bosons that mediate their interactions are discussed.

Keywords

Mass Formulas, Higgs Mechanism, Quantum Chromodynamics, Mass Generation

1. Introduction

The mass spectrum of elementary particles remains an unsolved mystery. There are no shared theoretical arguments that allow us to constrain the masses of elementary fermions (charged leptons, neutrinos, and quarks) or, what essentially amounts to the same thing, their coupling constants with the Higgs field. Nor are there any known compelling reasons supporting specific values for the masses of gauge bosons. In other words, the reasons why the masses of all these particles are those actually observed are unknown. The mystery is further complicated by a comprehensive inspection of the spectrum of elementary particles, which allows us to identify as many as four completely different mass scales [1].

The first mass scale, on the order of fractions of an eV, is that of neutrinos. Given the ongoing uncertainty about the actual mass levels of these particles, they will not be considered further in this article. However, what is interesting to note here is the departure from the next mass scale, which paradoxically includes only one element: the electron. The electron rest energy (about 0.511 MeV) is in fact roughly six to eight orders of magnitude above the upper mass limit of the heaviest neutrino, depending on the assumptions made about the mass hierarchy of these particles [2]. The electron, however, is about 210 times lighter than the muon, the next charged lepton, and about 280 times lighter than the pion, which is the lowest-mass hadronic state. This makes the electron unique. All remaining charged leptons and hadrons have masses ranging from the 105 MeV of the muon to approximately 10 GeV of the bare beauty hadrons. This mass range constitutes the third scale, above which there is a gap with complete absence of particles up to about 80 GeV. A fourth mass scale appears to include the W, Z_0, H_0 (Higgs) bosons and the top quark, with values between approximately 80 and 170 GeV. It is noteworthy that the photon γ has no mass and therefore also represents, in this context, a unique feature.

This overview considers elementary particles understood as kinematic elementary units, that is, minimal packages of physical quantities capable of independent spacetime propagation. This will, in effect, be the perspective we will adopt in this article. Naturally, it is possible to adopt a different approach, considering the basic states of the Standard Model (SM) as elementary. According to this view, hadrons are not elementary but are instead to be viewed as composed of (massless) gluons and quarks. The problem with this approach, however, is that it requires the introduction of a concept of quark mass that is necessarily dependent on a theoretical framework. Since the object of our study is the mass of elementary particles, we prefer to pursue a different path, which we will return to shortly. In any case, even the current quark masses presently lack a convincing explanation. It is common to distinguish between "light" (u, d, s) and "heavy" (c, b) quarks, with the top quark being a special case both for its enormous mass (171 GeV against the approximately 4 GeV attributed to the b quark) and for the fact that it does not form hadrons.

Thus, as defined above, there exists a "mass problem" [1] [3]-[9]. The aim of this article is to propose an approach to this problem, based on a specific hypothesis on the nature of the internal quantum numbers of the elementary fermions of the SM (neutrinos, charged leptons, and quarks). According to this hypothesis, each of these fermions carries three internal colors, each of which is further associated, according to appropriate rules, with three three-valued numerical indices. The fermionic flavor therefore corresponds to a specific configuration of internal colors and their associated indices. In the case of charged leptons and neutrinos, the indices are assigned symmetrically to all colors, so there is no privileged color that can appear as an "external" color; leptons are therefore color singlets insensitive to the strong interaction. In the case of quarks, however, the asymmetric assignment of indices to the various colors leads to a privileged color that appears as an "external" color. This latter is the well-known color contemplated by quantum chromodynamics (QCD), which appears as the source of the gluonic field. This hypothesis is a simplified version, for the specific purposes of this article, of a model of the systematics of elementary fermions illustrated in a previous work [10]. Although we recommend the interested reader to read that work for a suitable contextualization of our present argument, we will try to develop the reasoning in a completely self-contained form in the following.

The elementary fermions of the SM can interact with each other, and when the energy exchanged in the interaction is sufficiently high, their internal configuration, as defined above, can change. The energy thresholds for these processes define, through the uncertainty principle, the extent of the spatial region within which they occur. In a broad sense, this is the region within which the particle is localized by these interactions; this notion, however, does not imply the concept of a continuous extended charge distribution and therefore does not provide an upper limit on the value of the energy exchanged in the interaction.

Since the total internal color of a single lepton is zero, and the total manifest color of the valence quarks within a hadron must be zero, the mass spectra of leptons and pseudoscalar mesons follow a "three-and-two" formation rule, which gives rise to specific sequences. In this paper, we examine the formation sequences of the mass spectra of charged leptons and pseudoscalar mesons. In principle, the masses of pseudoscalar mesons can be related, through QCD modeling, to the masses of their valence quarks. Quark masses are therefore indirectly connected to the mass sequences investigated here.

Pools of fermionic configurations, represented in terms of internal colors and indices, can be associated with the weak interaction vertices. These pools are assigned energy reserves defined by the energy cost of these configurations. We interpret the Higgs mechanism as a conversion of these reserves into the mass of the gauge bosons mediating the interaction, which is zero before symmetry breaking. This argument plausibly also constrains the values of the weak coupling constant and the Weinberg angle.

The plan of the work is as follows. Section 2 illustrates the color and index configurations corresponding to the various fermionic flavors, and lays out the general basis of the argument. Section 3 develops a mass formula for charged leptons. Section 4 applies the "three-and-two" logic to the definition of a mass sequence for hadrons (pseudoscalar mesons). Section 5 presents a scheme for justifying the masses of gauge bosons. In Section 6 some possible cosmological connections are discussed, concerning the definition of the coupling constants at the big bang. Conclusions are presented in Section 7.

2. Indexes and Colors

The mass of an elementary fermion is a function of its flavor, which in turn is defined, according to the assumptions mentioned in the Introduction, by the internal configuration of indices and colors. Before turning to the mass problem, we must therefore illustrate how the systematics of elementary fermions emerges from the combinatorics of their internal configurations. As anticipated in the Introduction, our examination of this topic here is limited to a brief reminder aimed at our present purpose, which is to propose an elucidation of the mass trends of elementary particles. The interested reader is warmly invited to consult the original paper [10] in which the justification of the systematics of SM particles on these grounds is set out in greater detail.

In simplified form, the assumptions made to define the internal configuration of the elementary fermions of the SM can be stated as follows. First, each elementary fermion is associated with a triad of quantities that we call "colors." The relationship between these quantities is the same as that between the three fundamental colors in QCD; that is, the same as that between the elements of the fundamental irreducible representation of the SU_3 group of third-order unitary symmetry. It is assumed that the three colors associated with each fermion or antifermion are complementary to each other and that, while fermions are associated with the colors of the fundamental representation, antifermions are associated with the anticolors of its conjugate representation.

Secondly, each color (or anticolor) is associated with three numerical indices a, b, and c, each of which can assume the values −1, 0, or +1. If an index (for example, a) is zero for a given color, it is also zero for the other two; if, however, it is non-zero for a given color, it is also non-zero for the other two. The non-zero indices assume, for a given color, the same value; this common value, however, may differ for the three different colors.

The fermionic flavor is represented by the internal configuration of colors and indices in the following way. The number of non-zero indices defines the generation to which the fermion belongs: first-generation fermions have only one non-zero index; second-generation fermions have two, and third-generation fermions have three. For each given generation, the type of fermion (antifermion) is defined by the set of non-zero indices associated with the three colors (anticolors). If they are all equal to +1, we have the charged lepton (antilepton) of that generation. If they are all equal to −1, we have the neutrino (antineutrino) of that generation. These are the only combinations in which the three colors are not distinguished by different values of the indices associated with them; this symmetry is manifested in the fermion's overall colorlessness. That is, leptons are color singlets. In the other cases, two colors will have non-zero indices equal to +1 and one color will have index −1, or one color will have index +1 and the other two will have indices −1. The two cases correspond to the u-type and d-type quarks (antiquarks) of that specific generation. The colors (anticolors) are no longer equivalent, as there is a minority color (anticolor), different from the other two. This color (anticolor) manifests itself as the external color (anticolor) of the quark (antiquark); it is the usual color intended by QCD, *i.e.*, the source of the gluon field.

Leaving aside neutrinos, which will not be considered further in this article, it is possible to associate each elementary fermion of the SM (charged lepton or quark) with a spatial region of radius $r = q^2/mc^2$, where q is the fermion's charge and m its mass. The creation of that fermion in an interaction process requires the exchange of an energy equal to at least mc^2, given by the product of the interaction constant $q^2/\hbar c$ and the energy $\hbar c/r$ required by the uncertainty principle to resolve the radius r. In these processes, the production of "external" QCD color may or may not occur, and this leads us to consider the key role played by the electron mass scale.

For the electron, $q = -e$ (e = unit of electric charge) and therefore $r = r_c$, the classical radius of this particle. For energies > $\hbar c/r_c$ = 70 MeV, color is produced, which can remain "internal" or appear as an external color; in this second case, since a pair of external color-anticolor or a trio of complementary external colors must necessarily be produced, the value of 70 MeV must be doubled or tripled respectively, obtaining 140 MeV and 210 MeV [11]. Excitation processes of this type without the production of "bare" or "external" color are, for example, $e^+e^- \to \mu^+\mu^-$, or $e^-e^- \to e^-e^-\mu^+\mu^-$. External color is instead produced in processes such as $e^+e^- \to d^+d^-$, or $e^-e^- \to e^-e^-\pi^0$. The quarks generated in these processes, in fact, rearrange themselves into hadrons, and this circumstance leads to multihadronic production.

In a process such as $e^+e^- \to \mu^+\mu^-$, the number of non-zero indices varies (from one to two); consequently, the radius r varies from the value of the classical radius of the electron to that of the classical radius of the muon. However, processes like this do not alter the symmetry of the indices attributed to the various internal colors of the particle, so no "bare" or "external" color is produced. On the other hand, in a process such as $e^+e^- \to \pi^0$ the number of non-zero indices remains equal to one, but the values assumed by these indices become different for the various internal colors, and therefore "colored" quarks in the usual sense of the term are produced. These quarks rearrange themselves, giving rise to a bound state of the strong interaction, π^0. The reaction product constituted by this bound state is colorless, as were the reacting fermions. In these processes, the radius r varies as a consequence of the variation of both the charge q and the mass m. The mass passes from the initial value corresponding to the electronic mass to the final value corresponding to the mass of the generated quarks. The square charge q^2 passes from e^2 to a final value $\approx \hbar c$, typical of the strong interaction at the confinement limit. Using a perhaps more common lexicon, we have $r_c \to \hbar c/\Lambda_{QCD} \approx r_c/2$. The energy $\hbar c/(r_c/2)$ = 140 MeV $\approx \Lambda_{QCD}$ is approximately that of the pion triplet production.

Roughly speaking, in a reaction considered at the threshold energy in the creation of a fermion-antifermion pair (x and anti-x), the energy required for the actualization of the three internal colors is converted into the rest energy of the two members of the pair. Since the three colors involved are degenerate in energy (in order to assure the compatibility with the external color symmetry SU_3), we have a conversion rule of the type: $3m$(color-anticolor) $\to 2m(x)$, where $m(a)$ denotes the mass of a. This is the aforementioned "three-and-two" rule, which we will use later.

3. Charged Leptons

In this Section, we propose a possible mass sequence for charged leptons. Let i –

1 denote the ordinal number of the generation preceding that of the charged lepton whose mass m_i we wish to determine. Here, the "three-and-two" rule takes the form $3m(i-1) = 2m_i$, where $m(i-1)$ is the mass contribution of each color of the $(i-1)$-th generation, with $i \geq 2$. The determination of m_i is therefore reduced to that of the function $m(i-1)$.

Let $I(z)$ denote the set of non-zero indices (a, b, c) associated with the color (anticolor) z in the lepton (antilepton) of generation $(i-1)$. The cardinality of this set is clearly $\mathrm{Card}(I(z)) = i-1$. Let C (C') be the set of internal colors (anticolors) R, G, B (anti-R, anti-G, anti-B) associated with the lepton (antilepton) of generation $(i-1)$. Let us consider the Cartesian products:

$$I_1 = \prod_{z \in C \text{ or } C'} I(z);\; I_2 = \prod_{z \in C \cup C'} I(z) \tag{1}$$

Obviously, $\mathrm{Card}(I_1) = (i-1)^3$, $\mathrm{Card}(I_2) = (i-1)^6$. This result remains valid if in the expression of I_1 we replace C with C', that is, if we move from the lepton to the corresponding antilepton.

The elements of I_1 are all possible couplings between the non-zero indices (a, b, c) associated with all the colors (anticolors) of the lepton (antilepton) of generation $(i-1)$. These couplings define, as a whole, the interaction of the colors (anticolors) associated with the particle, in the process of its annihilation and conversion into a lepton-antilepton pair of the next generation. The interaction energy defines, through the uncertainty principle, the radius of the spatial region within which the internal colors are localized by this interaction. It is canonical to assume that the value of this radius is r_c, the classical radius of the electron, for the reasons seen in the previous Section. This leads to associating, to each element of I_1, a contribution to the function $m(i-1)c^2$ equal to $f\hbar c/r_c$, where f is an interaction constant. For the reasons already discussed, $f = q^2/\hbar c$, where q is the coupling constant between the colors at the confinement limit. Assuming $q^2 = \hbar c$, *i.e.*, a value corresponding to Λ_{QCD}, we have $f = 1$ and therefore an overall contribution $(i-1)^3\hbar c/r_c = (i-1)^3\alpha^{-1}m_1c^2$.

The elements of I_2 are all possible couplings between non-zero indices (a, b, c) associated with all the internal colors and anticolors of the lepton-antilepton pair of generation $(i-1)$. These couplings define, as a whole, the interaction of the colors (anticolors) associated with the pair in the process of its annihilation and conversion into a lepton-antilepton pair of the next generation. The energy contribution of each of these couplings is still $f\hbar c/r_c$, but now the coupling constant $f = q^2/\hbar c$ is different. Now, in fact, the radius of the spatial region involved is that at which two electric charges (the charged lepton and the corresponding antilepton) separate or annihilate each other, that is, their respective colors and anticolors separate or annihilate each other. In the case of the electron, this radius is the Compton wavelength r_c/α, so that $\hbar c/(r_c/\alpha) = m_1c^2 = f\hbar c/r_c$ and this relation implies $f = \alpha$, the fine structure constant. The contribution of I_2 to the function $m(i-1)c^2$ is therefore equal to $(i-1)^6 m_1c^2$. The total contribution of I_1 and I_2 is therefore $[(i-1)^3\alpha^{-1} + (i-1)^6]m_1c^2$.

However, this contribution still needs to be multiplied by all possible permutations of colors (anticolors) and indices. Restricting ourselves to cyclic permutations [10], only three color permutations are allowed. Therefore, the total contribution $[(i-1)^3\alpha^{-1}+(i-1)^6]m_1c^2$ needs to be multiplied by 3, yielding $3[(i-1)^3\alpha^{-1}+(i-1)^6]m_1c^2$. As for the permutations of non-zero indices, note that only the following cases are possible:

0 non-zero indices in the parent generation → 0 permutations $i-1=0$
1 non-zero indices in the parent generation → 1 permutations $i-1=1$
2 non-zero indices in the parent generation → 2 permutations $i-1=2$

The number of permutations is then expressed by $(i-1)$. Multiplying the resulting expression by $(i-1)$ gives the final expression ($i\geq 2$):

$$m_ic^2=\frac{3}{2}(i-1)\left[\frac{m_1c^2}{\alpha}(i-1)^3+m_1c^2(i-1)^6\right] \tag{2}$$

which translates the "three-and-two" rule for charged leptons. The results are:

$m_1 = 0.510998902 \pm 0.000000021$ MeV (assumed; source: PDG)
$m_2 = 105.804290 \pm 0.000004$ MeV PDG: 105.658357 ± 0.000005 MeV
$m_3 = 1778.71645 \pm 0.00007$ MeV PDG: $1776.99 + 0.29 - 0.26$ MeV

The differences Δm_i between the results of (2) and the corresponding experimental data are within αm_i, and can presumably be attributed to perturbative effects which will not be further analysed here. We draw the reader's attention to the difference between (2) and the certainly more popular relation proposed years ago by Barut on the basis of a semiclassical modelling [12] [13].

4. Hadrons

It is well known that it is not possible to assign a mass to quarks that has a model-independent meaning [2]. For this reason, we are not interested here either in the current masses (attributable to the coupling with the VEV of the Higgs field) or in the constituent masses related to specific quark models. Our interest is instead directed to an aspect directly accessible to empirical control and, at least ideally, independent of the model: the masses of the lightest truly neutral pseudoscalar mesons, consisting of a quark-antiquark pair of the same flavor. Therefore, rather than looking for an expression like (2) directly associated with elementary fermions, we instead look for a mass sequence for the mentioned meson states. In principle, from the estimate of the mass of these mesons and from their modeling in terms of QCD it should be possible to fit the masses of the individual quarks or, at least, fix these masses to given energy values. The values of the masses at other energies would then be obtainable by applying the equations of the renormalization semigroup. In this sense, our procedure is the reverse of that normally followed, for example, in non-perturbative lattice calculations. The reader may refer to [14] [15] for an alternative approach based instead on the extension to quarks of relations such as (2).

Our starting point is the assumption, explained in the previous Sections, that the externalization of color into an e^+e^- pair leads to the appearance of a series of hadronic states, the lightest of which is the pion, with rest energy ≈ $2\hbar c/r_c = 140$ MeV, in acceptable agreement (3.7%) with the experimental data. Let us consider the sequence:

π_0	$n = 0$
η	$n = 1$
η'	$n = 2$
$\eta_c\,(1s)$	$n = 3$
$\eta_b(1s)$	$n = 4$

We adopt the following mass formula:

$$M_n c^2 = 2\left(1+3a_n\right)\frac{\hbar c}{r_c} \tag{3}$$

where $a_0 = 0$, $a_1 = 1$ and, for $n \geq 1$:

$$a_{n+1} = 2\sum_{i=1}^{n} a_i + n - 1 \tag{4}$$

This formula expresses the successive tripling and doubling of "mass blocks" corresponding to truly neutral (flavorless) combinations of quarks, with a fundamental level $2\hbar c/r_c \approx 140$ MeV; thus, a version of the "three-and-two" rule adapted to the context under consideration. We obtain:

π_0	$M_0 = 140.05$ MeV	Experimental: 134.97 MeV	Difference: 3.7%
η	$M_1 = 560.2$ MeV	Experimental: 547.3 MeV	Difference: 2.3%
η'	$M_2 = 980.35$ MeV	Experimental: 958 MeV	Difference: 2.3%
$\eta_c\,(1s)$	$M_3 = 3081.1$ MeV	Experimental: 2979.7 MeV	Difference: 3.4%
$\eta_b(1s)$	$M_4 = 9383.35$ MeV	Experimental: 9388.9 MeV	Difference: $-6{\cdot}10^{-4}$

The discrepancies between the theoretical values obtained from the sequence and the experimental ones are probably at least partly explainable by electromagnetic effects, which we do not deal with here.

5. Gauge Bosons

Consider the interaction vertex at which a boson $B = W^{\pm}$, Z_0, H_0 of mass M_B couples two elementary fermions f_1, f_2. The energy cost of producing a color pair is, as seen in Section 3 (set I_1), $2\alpha^{-1}m_1c^2 = 140.05$ MeV. The idea we propose in this Section is that, in the false vacuum state of the Higgs mechanism, the Bf_1f_2 vertex consists of a pool of index and color configurations, each of which contributes equally, and independently of the others, to the minimum amount of energy required for the vertex to be actualized. This energy becomes the rest energy of the B gauge boson. We therefore have a pool of configurations for each B boson. The concurrence of the fermionic lines f_1, f_2 at the vertex selects the corresponding B

boson whose rest energy, initially zero, becomes finite and equal to the energy reserve constituted by the pool. The symmetry breaking is therefore interpreted in terms of this mass acquisition. This assumption connects the Higgs mechanism to the combinatorics of indices and colors from which, according to the scheme seen in Section 2, the fermionic flavors f_1 and f_2 emerge.

The pool associated with the W boson contains the 64 pairs of elementary fermions f_1, f_2 belonging to the same (unspecified) generation. Each of these couplings includes 3 × 3 = 9 couplings between the internal colors of f_1 and f_2 (considering three colors for each of them). Because the complete equivalence of colors and fermionic states, *i.e.* complete color and flavor symmetry, is assumed, the energy associated with all these couplings is $64 \times 9 \times 2\alpha^{-1}m_1c^2 = 80.67$ GeV.

This is therefore the energy that competes at the vertex of the process $W \rightarrow f_1 + f_2$. The W boson can be selected only by the couplings that satisfy the conservation of the electric charge q, that is, such that $q(W) = q(f_1) + q(f_2)$. This condition does not define the generation to which the fermion belongs (this fact is at the basis of flavour mixing) so that each fermion f_1 corresponds to a single fermion f_2, a linear combination of the fermions of the same charge belonging to the three generations (for example: if f_1 is the u quark, then f_2 is the d' quark, a combination of d, s, b). The number of possible a priori couplings between f_1 and f_2 therefore remains 64, despite the involvement of all three generations. In accordance with our hypothesis, the rest energy of W is therefore $M_Wc^2 = 80.67$ GeV. This value differs by 0.36% from the experimental value of 80.385 ± 0.015 GeV.

The pool associated with the Z_0 boson contains the 24 pairs consisting of the 24 elementary fermions of the three generations and their corresponding antiparticle. The energy assigned to the vertex under conditions of perfect symmetry becomes $24 \times 9 \times 2\alpha^{-1}m_1c^2 = 30.24$ GeV. However, the constraint is insensitive to the three cyclic color permutations applicable simultaneously to each member of a pair; indeed, the exchanged color remains null. Including these configurations in the energy reserve attributable to the vertex, this becomes 3 × 30.24 GeV = 90.72 GeV. This is the energy that competes for the vertex in the reaction $Z_0 \rightarrow f_1 + f_2$. Therefore, in accordance with our assumption, we have $M_{Z0}c^2 = 90.72$ GeV. This value differs by −0.51% from the experimental value of 91.1880 ± 0.0020 GeV.

Before the symmetry breaking, there are therefore energy reserves that will be subsequently converted into the masses of W^+, W^- and Z_0. The energy reserve constituted by their combination, which we will indicate with σ, clearly amounts to $(2M_W + M_{Z0})c^2 = 252.06$ GeV. If σ is identified as a component of the Higgs vacuum, pair creation processes can occur at the zero kinetic energy limit such as $\sigma \rightarrow H_0 + H_0$, where H_0, the Higgs boson, is the quantum of the field. The mass of this boson then turns out to be half of σ, that is: $M_{H0}c^2 = 126.03$ GeV. This value differs from the experimental one, 125.35 ± 0.15 GeV, by 0.54%.

If we take the previously considered energy reserve of 80.67 GeV and triple it by including in it, as distinct, the configurations deriving from the three generation of elementary fermions, we obtain a new reserve σ' of 3 × 80.67 GeV = 242.01

GeV. Before symmetry breaking, the reserves σ and σ' are energy amplitudes of virtual fluctuations. By averaging them in quadrature, we obtain the expectation value:

$$\sqrt{\frac{(242.01\ \text{GeV})^2+(252.06\ \text{GeV})^2}{2}}=247.09\ \text{GeV} \tag{5}$$

which can be identified with the VEV of the Higgs field. The value (5) differs from the usually accepted one of 246 GeV by 0.44%.

An interesting mass conversion process that can be hypothesized is: $2\sigma \to W^+ + W^- + t^+ + t^-$, (or the equivalent, even more symmetrical $\sigma + Z_0 = W^+Z_0W^-Z_0 \to t^+ + t^-$), where t represents the top quark. We then have $M_tc^2 = \sigma - M_Wc^2 = (252.06 - 80.67)$ GeV = 171.39 GeV. This result is superimposable on the experimental one 171.77 ± 0.38 GeV. Since the top quark does not form hadrons due to its fast decay, it is the only one whose mass can be obtained directly from weak sector through the conversion of σ.

To summarize: while all the pools of configurations which are percursors of the gauge bosons and the t^+t^- pair are mutated in themselves by the cyclic permutations of the internal colors of f_1 and f_2, their behavior with respect to the conjugation of those same colors is different. The precursor pool of the W is mutated into the pool of conjugated configurations. This property is inherited from the W since a conjugation of the colors of the fermions f_1, f_2 concurrent at a vertex mediated by the W converts these fermions into their respective antifermions, and hence the W into its conjugate. The σ pool is symmetric with respect to the conjugation of the colors of f_1, f_2 and this property is inherited from the two H_0 bosons that originate from it. In fact, a conjugation of the colors of the fermions f_1, f_2 concurrent at a vertex mediated by H_0 converts these fermions into their respective antifermions, but leaves H_0 unchanged. By applying the same reasoning we note that the precursor of Z_0 is self-conjugated, and that this property is inherited from Z_0. The pool $\sigma Z_0 = (W^+Z_0)(W^-Z_0)$ undergoes, under the conjugation of the colors of f_1, f_2, the interchange of the components (W^+Z_0) and (W^-Z_0); this property is shared by their descendants t^+ and t^-, which are interconverted by conjugation. The pool σ' is converted into the pool of conjugated configurations. The VEV is therefore the composition of a self-conjugated part (σ) and another (σ') that is not. Only the former contributes to the mass of H_0.

It is certainly superfluous to underline the hypothetical and speculative nature of the scheme outlined in this Section, which we present merely in the hope of arousing interest for discussion. However, in defense of our argument, we believe it is useful to point out that the suggested assumption seems to satisfactorily constrain the values of the masses generated by the Higgs mechanism, which would otherwise appear as free parameters. Our argument leaves out the photon γ because it remains subject to an exact U_1 gauge symmetry, and therefore maintains zero mass. We also believe it is appropriate to recall that, from the standard formulation of the Higgs mechanism:

$$\mathrm{VEV} = \frac{\sqrt{2}c^2}{g_{weak}} M_W c^2 \tag{6}$$

If the values of VEV and M_W are assumed to be constrained by the present argument, through (6) it is possible to estimate the weak coupling constant g_{weak}. From this constant and from the expression $e = g_{weak}\sin(\theta_W)$, also derived from the Higgs mechanism, which connects it to the elementary electric charge e, it is then possible to derive the Weinberg angle θ_W. If the reasoning presented here is correct, the value of these parameters is then constrained by the existence of internal colors, through the "three-and-two" rule which takes, in this context, the form of the generation of σ by triplings and its subsequent halving.

6. On the Genealogy of Coupling Constants

As seen in Section 2, the color property manifests itself on a spatial scale superimposable on the classical electron radius, r_c. The relation between the energy associated with this manifestation, $Mc^2 = \hbar c/r_c$, and the scale r_c can be written in a form that makes the coupling constant $q^2/\hbar c$ explicit, namely $Mc^2 = (q^2/\hbar c)(\hbar c/r_c)$, where, in this specific case, $q^2 = \hbar c$. This relation can be generalized in the form $Mc^2 = g(\hbar c/r)$, where the right-hand side now represents the energetic cost of creating a set of physical quantities that, in the context of spontaneous quantum fluctuations, dissociate and recombine on a spatial scale r. The position $g = q^2/\hbar c$ is still possible, where the square charge q^2 now depends on the interaction that mediates the dissociation and recombination of those quantities. With this choice, the particular case in which the quantities involved are the internal colors is characterized by having $Mc^2 = 70$ MeV, $r = r_c$ and $q^2 = \hbar c$. When the colors are manifested externally, this description applies to a specific interaction, which is the strong interaction at the confinement scale (up to factors of order 1, it is in fact $Mc^2 = \Lambda_{QCD}$). The case of electric charges of the two signs corresponds instead to $M = m_1$, the mass of the electron, $r = r_c$ and $q^2 = \alpha\hbar c$, where α is the renormalized fine structure constant.

We note that the localization of an energy $Mc^2 = 70$ MeV on a spatial scale r_c necessarily implies a gravitational self-interaction energy:

$$\frac{G}{r_c}\left(\frac{\hbar}{r_c c}\right)^2 = \frac{\hbar c}{R} \tag{7}$$

where G is the gravitational constant, by virtue of the universality of the gravitational interaction. The left-hand side of (7) can also be written in the form $(q^2/\hbar c)(\hbar c/r_c)$, setting $q^2 = G(\hbar/r_c c)^2$. The interaction involved is now, of course, the gravitational one. It turns out that the coupling constants of three different interactions: strong (at the confinement limit), electromagnetic and gravitational are different expressions of the single constant g that appears in the general relation $Mc^2 = g(\hbar c/r_c)$. In principle, a running of g can exist. In fact, let us consider the Callan-Symanzik equation in the form:

$$g = \frac{g_0}{1 - a\, g_0 \log\left(\frac{E}{E_0}\right)} \tag{8}$$

where g_0 is the coupling constant at the infrared cutoff defined by (7):

$$E_0 = \frac{\hbar c}{R}\ ; \quad g_0 = g\left(E_0\right) = \frac{G\left(\hbar/cr_c\right)^2}{\hbar c} \tag{9}$$

and $E = \hbar c/x$ is the energy associated, by the uncertainty principle, with the spatial domain of extension x. For $x = R$, it is $E = E_0$ and therefore $g = g_0$. For $x = r_c$, it is $E = E_f = \hbar c/r_c >> E_0$, so $g \sim g_f = -1/[a \log(E_f/E_0)]$. If we require that g_f be the value of the coupling constant of the electromagnetic interaction, then $g_f \sim \alpha$. This implies $a < 0$. Setting $a = -1/\log(2)$, we have $g_f = \alpha$, as required, if:

$$R = 2^{\frac{1}{\alpha}}\, r_c \tag{10}$$

Up to factors in the order of unity, we can interpret R as the radius of curvature of cosmological space. The radius R can then be connected to the cosmological constant Λ through the natural relation $\Lambda = 3/R^2$. The Equation (7) then allows a theoretical prediction of the value of Λ, of course in order of magnitude, the result of which is 4.1×10^{-56} cm^{-2}, being $R = 3.03 \times 10^{40}\ r_c = 8.54 \times 10^{27}$ cm. This result is in agreement, in order of magnitude, with that provided by cosmological observations, which amounts to 1.10×10^{-56} cm^{-2} [16]. On the other hand, inserting into (10) the experimental value of R, estimated from the experimental value of $\Lambda = 1.10 \times 10^{-56}$ cm^{-2} through the relation $R = (3/\Lambda)^{1/2} = 1.65 \times 10^{28}$ cm, and the nominal value of $r_c = 2.81 \times 10^{-13}$ cm, we obtain $\alpha = 1/135.44$. This result is superimposable with the running value of the electromagnetic fine structure constant at the energy E_f. The "preferred" role of the binary logarithmic base seems to allude to an informational meaning of $1/\alpha$, linked to the localization of the charges in space. This allusion suggests the following speculation.

Let us imagine that the initial state of the Universe is represented by a maximally symmetric space with constant radius of curvature x, quantum variable delocalized on the interval $[0, R]$. This space will be, by hypothesis, a reservoir of energy in the form of quanta vibrating in the ground state with frequency c/x, maximally delocalized. This results in a condition of maximum isotropy and spatial homogeneity. Each value of x will correspond to a value of g according to (8). As x decreases, the energy E for each quantum will increase, but this increase will be compensated by the decrease in the number N of fundamental oscillations, so as to keep the energy balance unchanged.

Now, the point is that only for $x \le r_c$ will the energy E be sufficient to be converted into processes of creation of internal colors and charges. Therefore, only for $x \le r_c$ can the creation of material particles take place. On the other hand, while color charges manifest themselves confined in globally neutral or "colorless" aggregations, the genesis of electric charges requires an open space in which the formation of infinitely extendable electric lines of force is possible. This space must be any space tangent to the closed space of radius $x = r_c$. Such "private" tangent spaces, each associated with a fundamental observer, will be connected to each other by global coordinate translations on the "public" space of radius $x = r_c$, for example by projectivity. The private space of a fundamental observer will then be the phenomenal cosmological space, within which he/she will coordinate remote events up to a "cosmological horizon" placed at distance R, the infrared cutoff established by (7). According to conventional cosmology, this space will be expanding.

The initial situation, represented by the nucleation of particles within a domain of extension $\sim r_c$ in private space, will constitute a non-singular big bang. Spaces of radius x with $r_c < x \leq R$ will constitute the "pre-big bang" state of cosmological evolution. It should be noted that, as a consequence of the homogeneity and isotropy of the physical situation in these spaces, the big bang will also be homogeneous and isotropic. However, since the nucleation of charges and particles is a statistical phenomenon, it will introduce inhomogeneities that will become the seeds for the subsequent evolution of structures.

In the transition from $x = R$ to $x = r_c$ the number N of fundamental oscillations undergoes a decimation and the binary logarithm of the selection ratio, as can be easily seen from (10), is $1/a$. This number therefore represents the information acquired in the process of selection of the fundamental oscillations, which constitutes the premise for the nucleation of charges in the big bang and the emergence of the phenomenal world.

7. Conclusions

The astonishing predictive power of the Standard Model is powerless to explain its free parameters, and the numerous numerical coincidences between these parameters that appear physically significant; but also to physically justify its very basis states. In this article, we have quietly addressed at least two of these "mysteries". The first, which has remained unsolved since the time of the historic experiment by Pancini, Piccioni and Conversi [17], is the existence of a replica of the electron, the muon. The question arises as to how it is possible for two particles, characterized by the same behavior in relation to their main interaction with the external world, the electromagnetic one, to have such a significant difference in mass. If this difference is attributable to their different coupling with the VEV of the Higgs field, as is usually accepted today, it must originate from their internal characteristics that have no effect on the dynamics expressed by the SM Lagrangian. Or at least, with no effect other than the mere definition of the fermionic flavor; which makes these features uninvestigable through extensions of SM dynamics.

Another disturbing mystery is the concordance of the classical radius of the electron with the effective action radius of the strong force. We have hypothesized an internal color of elementary fermions that can be excited above an energy threshold given by the reciprocal of the classical radius of the electron, expressed in natural units. The excitation of this degree of freedom can lead to the production of states in which the color remains unobservable, the lightest of which is represented by the muon. Or it can lead to the production of bound states of objects with external color (quarks), the lightest of which is the pion. As illustrated in Sections 1-3, it is possible on this basis to explain both the existence of the muon and its difference in mass with respect to the electron. But we also have a common basis for the mass spectra of hadrons and charged leptons, including the muon; and, therefore, a representation of the fundamental unity of the electromagnetic force and the strong force that appears to be deeper than that obtainable from the—in any case fruitful—unification of their symmetry groups. The first, in fact, seems to constitute the root and the necessary completion of the second. For the reasons already expressed, this completion does not require a modification of the SM Lagrangian.

As can be easily verified by retracing the line of argument, the different mass scales discussed in the Introduction all ultimately reduce to one: the electron mass m_1. If we set $m_1 = 0$, the mass of all charged leptons is automatically zeroed as a consequence of (2). Furthermore, the color excitation energy scale $\alpha^{-1} m_1 c^2$, which is the basis of (3), is zeroed; the masses of all pseudoscalar mesons are, consequently, zeroed, because $r_c = \infty$. This in turn implies an exact flavor unitary symmetry, which reduces the quark mass spectrum to a single point. This symmetry expresses the invariance of the fermionic mass with respect to the value of the indices associated with the internal colors, with the consequence that the only surviving mass value for quarks should be the same as that of the electron, *i.e.*, zero. Finally, the position $m_1 = 0$ implies the cancellation of the energy reserves associated with the weak interaction vertices, with the consequent cancellation of the masses of the gauge bosons and of the VEV (Section 5).

When approaching the study of the Higgs mechanism for the first time, it is almost impossible to avoid a feeling of discomfort; in fact, one first hypothesizes a cosmic state of perfect gauge symmetry with zero masses, only to then artificially break this symmetry through a redefinition of the vacuum. The narrative presented in this paper can perhaps help in overcoming this uncomfortable condition. In fact, saying that the expectation value of the vacuum is different from zero is equivalent to affirming nothing more than the mass of the electron is finite. This equivalence makes no longer necessary to consider the breaking of symmetry as an actual physical event that occurred in the past, because it can be reinterpreted as a mere logical step necessary for the reconstruction of the necessary relationships between the masses of elementary particles. Relationships that are expressed by Equations (2), (3) and by the relations reported in Section 5.

Naturally, this line of reasoning does not exclude the possibility that in the Universe's very remote past, a few moments after the Big Bang, the state of matter could indeed be expressed by exactly gauge-invariant laws. And that, subsequently, a quantum fluctuation actualized by a quantum jump induced, as a real physical phenomenon, a redefinition of the vacuum. The point we wish to emphasize, however, is that in the present state of affairs, the true nature of the symmetry breaking seems more easily interpreted as a logical step consistent with the reconstruction of a general architecture of masses. This architecture would be necessitated by the existence of internal degrees of freedom of elementary fermions, such as the aforementioned indices and internal colors.

From this perspective, the symmetric state would be that of energetically degenerate and non-interacting configurations of colors and indices, which give rise to agglomerations that constitute the precursors of both elementary fermions (single or associated in hadrons) and their interaction vertices. The essence of the Higgs mechanism then becomes the conversion of the energy of these agglomerations of properties (indices and colors) into spatially localizable blocks of mass, that is, into the elementary particles described as the basis states (elementary fermions and gauge bosons) of the Standard Model.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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