Physical Vacuum as the Source of Standard Model Particle Masses

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Received 1 February 2011, Accepted 10 February 2011, Published 25 May 2011

Abstract: We present an approach of mass generation for Standard Model particles in which fermions acquire masses from their interactions with physical vacuum and gauge bosons acquire masses from charge fluctuations of vacuum. A remarkable fact of this approach is that left-handed neutrinos are massive because they have a weak charge. We obtain consistently masses of electroweak gauge bosons in terms of fermion masses and running coupling constants of strong, electromagnetic and weak interactions. On the last part of this work we focus our interest to present some consequences of this approach as for instance we first show a restriction about the possible number of fermion families. Next we establish a prediction for top quark mass and finally fix the highest limit for the summing of the square of neutrino masses.

Keywords: Particle Mass Generation; Physical Vacuum; Standard Model without Higgs Sector; Self-Energy, Polarization Tensor
PACS (2010): 12.60.Fr; 14.80.Bn; 12.15.Ff

1. Introduction

The Standard Model (SM) is a gauge theory based on the $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge group. In this model particles acquire masses by means of implementation of the electroweak symmetry spontaneous breaking using Higgs mechanism. This mechanism is based on the fact that the potential must be such that one of neutral components of the Higgs field doublet acquires spontaneously a non-vanishing vacuum expectation value. Since the vacuum expectation value of the Higgs field is different from zero, the Higgs field vacuum can be interpreted as a medium with a net weak charge. On this way the $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge symmetry is spontaneously broken into the

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$SU(3)_C \times U(1)_{em}$ symmetry [1]. In current picture of Higgs mechanism particle masses are generated by interactions of particles with weakly charged Higgs field vacuum [2].

We present an approach for particle mass generation [3] in which the role of Higgs field vacuum is played by physical vacuum. This physical vacuum is understood as a virtual medium at zero temperature which is formed by fermions and antifermions interacting among themselves by exchanging gauge bosons. We assume that the fundamental particle model to describe dynamics of physical vacuum is the Standard Model without the Higgs Sector (SMWHS). We assume that to every fermion flavor in physical vacuum we associate a chemical potential μ_f which describes an excess of antifermions over fermions in the vacuum.

On this approach, masses for fermions are generated from their self-energies which represent fundamental interactions of fermions with physical vacuum [4]. On the other hand, masses for gauge bosons are generated from charge fluctuations of physical vacuum which are described by vacuum polarization tensors [4]. An outstanding fact of our approach is that left-handed neutrinos are massive because they have weak charge. The weak interaction among left-handed neutrinos and physical vacuum is a source for neutrino masses. We find that masses of fermions and gauge bosons are functions of vacuum fermionic chemical potentials μ_f which are unknown input parameters here. This fact let us write masses for electroweak gauge bosons in terms of fermion masses and running coupling constants of strong, electromagnetic and weak interactions. Additionally we establish a prediction for top quark mass and fix the highest limit for the summing of the square of neutrino masses.

Before considering the dynamics of real physical vacuum which is described by the SMWHS, in section 2 we first study a more simple case in which the dynamics of the vacuum is described by a non-abelian gauge theory and in this context masses of fermions and gauge bosons are generated from vacuum. In section 3 we regard the SMWHS as the model which describes the dynamics of the physical vacuum and we achieve masses for fermions (quarks and leptons) and electroweak gauge bosons ($W^{\pm}$ and Z^0). This procedure allows us to consistently write electroweak gauge boson masses in terms of the fermion masses and running coupling constants of three fundamental interactions. In section 4 we first focus our interest to find a restriction about the possibility of having a new fermion family, next establish a prediction for top quark mass and finally fix the highest limit for the summing of the square of neutrino masses. Our conclusions are summarized in section 5.

2. Mass Generation in a Non-Abelian Gauge Theory

We initially study the case in which the dynamics of vacuum is described by means of a gauge theory invariant under the non-abelian gauge group $SU(N)$. Consequently the physical vacuum is thought to be a quantum medium at zero temperature constituted by massless fermions and antifermions interacting among themselves through the $N-1$ massless gauge bosons. We assume that there is an excess of antifermions over fermions in the vacuum. This antimatter-matter asymmetry of vacuum is described by non-vanishing fermionic chemical potentials μ_{f_i}, where f_i represent different fermion species. For simplicity, we take $\mu_{f_1} = \mu_{f_2} = \ldots = \mu_f$. Fermion mass is generated by the $SU(N)$ gauge interaction among massless fermion with vacuum. The charge fluctuations of vacuum is a source of gauge boson mass.

We follow the next general procedure to calculate particle masses: (i) Initially we write one-loop self-energies and one-loop polarization tensors at finite density and finite temperature. (ii) Next we calculate dispersion relations by obtaining poles of fermion and gauge boson propagators. (iii) Starting from these dispersion relations we obtain fermion and gauge boson effective masses at finite density and finite temperature. (iv) Finally we identify these particle effective masses at zero temperature as physical particle masses. This identification can be performed reasons by the virtual medium at zero temperature represents the physical vacuum.

It is well known in the context of quantum field theory at finite temperature and density that as a consequence of statistical interactions among massless fermions with a medium at temperature T and fermionic chemical potential μ_f, fermions acquire an effective mass M_F given by [5]

$$M_F^2(T, \mu_f) = \frac{g^2 C(R)}{8} \left(T^2 + \frac{\mu_f^2}{\pi^2} \right), \tag{1}$$

where g is the interaction coupling constant and $C(R)$ is the quadratic Casimir invariant of the representation of the $SU(N)$ gauge group. For the fundamental representation the quadratic Casimir invariant is given by $C(R) = (N^2 - 1)/2N$ [6]. The expression for M_F^2 given by (1) is in agreement with [7-10]. For the case in which the interaction among the massless fermions with the medium is mediated by $U(1)$ Abelian gauge bosons, the effective mass of fermions is also given by the expression (1) with $g^2C(R) \to e^2$, being e the interaction coupling constant associated with the $U(1)$ gauge group. The effective mass of fermions is gauge invariant due to that it was obtained at leading order in temperature and chemical potential [10]. We are interested in the effective mass at $T = 0$ which corresponds precisely to the case in which the vacuum is described by a virtual medium at zero temperature. For this case the effective mass of the fermion is

$$M_F^2(0, \mu_F) = M_F^2 = \frac{g^2 C(R)}{8} \frac{\mu_f^2}{\pi^2}. \tag{2}$$

For the limit $k \ll M_F$ it is possible to write the fermion dispersion relation as [3]

$$\omega^2(k) = M_F^2 \left[1 + \frac{2}{3} \frac{k}{M_F} + \frac{5}{9} \frac{k^2}{M_F^2} + \ldots \right]. \tag{3}$$

It is well known that the relativistic energy in vacuum for a massive fermion at rest is $\omega^2(0) = m_f^2$. It is clear from (3) that if $k = 0$ then $\omega^2(0) = M_F^2$ and thereby we can identify the fermion effective mass at zero temperature as the rest mass of fermion, i. e. $m_f = M_F$. For this reason we can conclude that the gauge invariant fermion mass, which is generated from the $SU(N)$ gauge interaction of the massless fermion with the vacuum, is

$$m_f^2 = \frac{g^2 C(R)}{8} \frac{\mu_f^2}{\pi^2}. \tag{4}$$

On the other hand, as a consequence of charge fluctuations of the medium, the non-Abelian gauge boson acquires an effective mass $M_{B(na)}$ given by [5]

$$M_{B(na)}^2(T,\mu_f) = \frac{1}{6} N g^2 T^2 + \frac{1}{2} g^2 C(R) \left[\frac{T^2}{6} + \frac{\mu_f^2}{2\pi^2} \right], \tag{5}$$

where N is the gauge group dimension. The non-Abelian effective mass (5) was also calculated in [3]. If some dynamics of the medium were described by means of a $U(1)$ gauge invariant theory, the Abelian gauge boson would have acquired an effective mass $M_{B(a)}$ given by [5]

$$M_{B(a)}^2(T,\mu_f) = e^2 \left[\frac{T^2}{6} + \frac{\mu_f^2}{2\pi^2} \right]. \tag{6}$$

The Abelian effective mass (6) is in agreement with [11]. For the vacuum as described by a virtual medium at $T = 0$, the non-Abelian gauge boson effective mass generated by the quantum fluctuations of the vacuum is

$$M_{B(na)}^2(0,\mu_f) = M_{B(na)}^2 = g^2 C(R) \frac{\mu_f^2}{4\pi^2}, \tag{7}$$

and the Abelian gauge boson effective mass is

$$M_{B(a)}^2(0,\mu_f) = M_{B(a)}^2 = e^2 \frac{\mu_f^2}{2\pi^2}, \tag{8}$$

in agreement with the result obtained at a finite density and zero temperature [12]. The dispersion relations for the transverse and longitudinal propagation modes are given by [13]

$$\omega_L^2 = M_B^2 + \frac{3}{5} k_L^2 + \ldots, \tag{9}$$

$$\omega_T^2 = M_B^2 + \frac{6}{5} k_T^2 + \ldots, \tag{10}$$

for $k \ll M_{B_\mu}$ limit. It is clear from (9) and (10) that for $k = 0$ then $\omega^2(0) = M_B^2$ and we can recognize the gauge boson effective mass as a physical gauge boson mass. The non-Abelian gauge boson mass is

$$m_{B(na)}^2 = M_{B(na)}^2 = g^2 C(R) \frac{\mu_f^2}{4\pi^2}, \tag{11}$$

and the Abelian gauge boson mass is

$$m_{B(a)}^2 = M_{B(a)}^2 = e^2 \frac{\mu_f^2}{2\pi^2}. \tag{12}$$

We observe that the gauge boson mass is a function on the chemical potential that is a free parameter on this approach. We can notice that if the fermionic chemical potential has an imaginary value then the gauge boson effective masses given by (11) and (12) would be negative [14].

3. Fermion and Electroweak Gauge Boson Masses

In this section we present the way how fermions and gauge bosons masses are generated for the case in which the dynamics of physical vacuum is described by mean of the SMWHS. The dynamics of physical vacuum associated with the strong interaction is described by Quantum Chromodynamics (QCD), while the electroweak dynamics of the physical vacuum is described by the $SU(2)_L \times U(1)_Y$ electroweak standard model without a Higgs sector. The physical vacuum is assumed to be a medium at zero temperature constituted by quarks, antiquarks, leptons and antileptons interacting among themselves through gluons G (for the case of quarks and antiquarks), electroweak gauge bosons $W^{\pm}$, gauge bosons W^3 and gauge bosons B. On this quantum medium there is an excess of antifermions over fermions. This fact is described by non-vanishing chemical potentials associated with different fermion flavors. Chemical potentials for six quarks are represented by $\mu_u, \mu_d, \mu_c, \mu_s, \mu_t, \mu_b$. For chemical potentials of charged leptons we use the notation μ_e, μ_μ, μ_τ and for neutrinos $\mu_{\nu_e}, \mu_{\nu_\mu}, \mu_{\nu_\tau}$. These non-vanishing chemical potentials are free parameters.

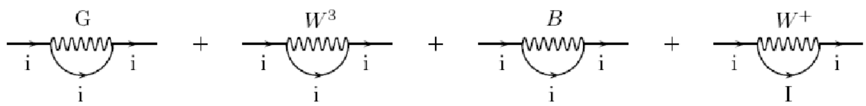

Figure 1 Feynmann diagrams contributing to the self-energy of the left-handed quark i.

Considering Feynman rules of the SMWHS we can calculate self-energies for every of the six quark flavors. Feynman diagrams at one-loop order which contribute to the self-energy of the left-handed quark i ($i = u_L, c_L, t_L$) are shown in Figure 1. Using the general expression for fermion mass given by (4), we obtain masses for left-handed quarks [3]

$$m_i^2 = \left[\frac{4}{3}g_s^2 + \frac{1}{4}g_w^2 + \frac{1}{4}g_e^2\right]\frac{\mu_{i_L}^2}{8\pi^2} + \left[\frac{1}{2}g_w^2\right]\frac{\mu_{I_L}^2}{8\pi^2}, \tag{13}$$

$$m_I^2 = \left[\frac{4}{3}g_s^2 + \frac{1}{4}g_w^2 + \frac{1}{4}g_e^2\right]\frac{\mu_{I_L}^2}{8\pi^2} + \left[\frac{1}{2}g_w^2\right]\frac{\mu_{i_L}^2}{8\pi^2}, \tag{14}$$

where g_s, g_w and g_e are running coupling constants of strong, weak and electromagnetic interactions, respectively. On expressions (13) and (14) the couple of indexes (i, I) runs over left-handed quarks (u_L, d_L), (c_L, s_L) and (t_L, b_L). We can identify within (13) and (14) contributions for masses of left-handed quarks from G, W^3, B and $W^{\pm}$ interactions among left-handed quarks and physical vacuum.

If we call

$$a_q = \frac{1}{8\pi^2}\left[\frac{4}{3}g_s^2 + \frac{1}{4}g_w^2 + \frac{1}{4}g_e^2\right], \tag{15}$$

$$b_q = \frac{1}{8\pi^2}\left[\frac{1}{2}g_w^2\right], \tag{16}$$

it is easy to prove that quark masses (13) and (14) lead to

$$\mu_{u_L}^2 = \frac{a_q m_u^2 - b_q m_d^2}{a_q^2 - b_q^2}, \tag{17}$$

$$\mu_{d_L}^2 = \frac{-b_q m_u^2 + a_q m_d^2}{a_q^2 - b_q^2}, \tag{18}$$

and we can obtain similar expressions for other two quark doublets (c_L, s_L) and (t_L, b_L).

Masses for left-handed leptons are obtained considering contributions to lepton self-energies. We obtain that these masses are given by [3]

$$m_i^2 = \left[\frac{1}{4}g_w^2\right]\frac{\mu_{i_L}^2}{8\pi^2} + \left[\frac{1}{2}g_w^2\right]\frac{\mu_{I_L}^2}{8\pi^2}, \tag{19}$$

$$m_I^2 = \left[\frac{1}{4}g_w^2 + \frac{1}{4}g_e^2\right]\frac{\mu_{I_L}^2}{8\pi^2} + \left[\frac{1}{2}g_w^2\right]\frac{\mu_{i_L}^2}{8\pi^2}, \tag{20}$$

where the couple of indexes (i, I) runs over leptons (ν_{e_L}, e_L), (ν_{μ_L}, μ_L) and (ν_{τ_L}, τ_L). A remarkable fact is that left-handed neutrinos are massive because they have weak charge. As we can observe from (19),W^3 and $W^{\pm}$ interactions among massless neutrinos with physical vacuum are the origin of left-handed neutrinos masses.

If we make the following definitions

$$a_l = \frac{1}{8\pi^2}\left[\frac{1}{4}g_w^2\right], \tag{21}$$

$$b_l = \frac{1}{8\pi^2}\left[\frac{1}{2}g_w^2\right], \tag{22}$$

$$c_l = \frac{1}{8\pi^2}\left[\frac{1}{4}g_w^2 + \frac{1}{4}g_e^2\right], \tag{23}$$

then lepton masses (19) and (20) lead to

$$\mu_{\nu_L}^2 = \frac{c_l m_\nu^2 - b_l m_e^2}{a_l c_l - b_l^2}, \tag{24}$$

$$\mu_{e_L}^2 = \frac{-b_l m_\nu^2 + a_l m_e^2}{a_l c_l - b_l^2}, \tag{25}$$

and it is possible to write similar expressions for other two lepton doublets (ν_{μ_L}, μ_L) and (ν_{τ_L}, τ_L).

We observe that for five of six fermion doublets the square of the left-handed chemical potential associated to down fermion of each doublet has a negative value. This behavior is observed for the case in which there is a large difference between masses of both fermions of the same doublet. Since up and down quarks have approximately equivalent masses, the mentioned behavior is not observed for the left-handed quark doublet formed by up and down quarks. For this case chemical potentials associated to these two left-handed quarks are positive.

On the other hand, applying expressions (11) and (12) for the SMWHS case, we obtain masses for gauge bosons [3]

$$M^2_{W^\pm} = \frac{g_w^2}{2}\ \frac{\mu^2_{u_L} + \mu^2_{d_L} + \mu^2_{c_L} - \mu^2_{s_L} + \mu^2_{t_L} - \mu^2_{b_L} + \sum_{i=1}^{3}(\mu^2_{\nu_{i_L}} - \mu^2_{e_{i_L}})}{4\pi^2}, \tag{26}$$

$$M^2_{W^3} = \frac{g_w^2}{4}\ \frac{\mu^2_{u_L} + \mu^2_{d_L} + \mu^2_{c_L} - \mu^2_{s_L} + \mu^2_{t_L} - \mu^2_{b_L} + \sum_{i=1}^{3}(\mu^2_{\nu_{i_L}} - \mu^2_{e_{i_L}})}{2\pi^2}, \tag{27}$$

$$M^2_{B} = \frac{g_e^2}{4}\ \frac{\mu^2_{u_L} + \mu^2_{d_L} + \mu^2_{c_L} - \mu^2_{s_L} + \mu^2_{t_L} - \mu^2_{b_L} + \sum_{i=1}^{3}(\mu^2_{\nu_{i_L}} - \mu^2_{e_{i_L}})}{2\pi^2}, \tag{28}$$

where the summation runs over the three leptons families. It is important to remember that if the fermionic chemical potential has an imaginary value then its contribution to the gauge boson effective mass, as in the case (11) or (12), is negative. This fact means that finally the contribution from every fermionic left-handed chemical potential to masses of gauge bosons is always positive.

For well known physical reasons W^3_μ and B_μ gauge bosons are mixed. After diagonalization of the mass matrix, we get physical fields A_μ and Z_μ corresponding to photon and neutral Z^0 boson of mass M_Z respectively, through relations [15, 16]

$$M_Z^2 = M_W^2 + M_B^2, \tag{29}$$

$$\cos\theta_w = \frac{M_W}{M_Z} \quad , \quad \sin\theta_w = \frac{M_B}{M_Z}, \tag{30}$$

where θ_w is the weak mixing angle

$$Z^0_\mu = B_\mu \sin\theta_w - W^3_\mu \cos\theta_w, \tag{31}$$

$$A_\mu = B_\mu \cos\theta_w + W^3_\mu \sin\theta_w. \tag{32}$$

Substituting expressions (17), (18), (24), (25) for fermionic left-handed chemical potentials into expressions (26), (27), (28) we obtain masses of electroweak gauge bosons W and Z in terms of fermion masses and running coupling constants of strong, electromagnetic and weak interactions. Masses of electroweak gauge bosons can be written as [3]

$$M_W^2 = g_w^2(A_1 + A_2 + A_3 - A_4), \tag{33}$$

$$M_Z^2 = (g_e^2 + g_w^2)(A_1 + A_2 + A_3 - A_4), \tag{34}$$

where the parameters A_1, A_2, A_3 and A_4 are

$$A_1 = \frac{m_u^2 + m_d^2}{B_1}, \tag{35}$$

$$A_2 = \frac{m_c^2 - m_s^2 + m_t^2 - m_b^2}{B_2}, \tag{36}$$

$$A_3 = \frac{3(m_e^2 + m_\mu^2 + m_\tau^2)}{B_3}, \tag{37}$$

$$A_4 = \frac{(3 + g_e^2/g_w^2)(m_{\nu_e}^2 + m_{\nu_\mu}^2 + m_{\nu_\tau}^2)}{B_3}, \tag{38}$$

and where

$$B_1 = \frac{4}{3}g_s^2 + \frac{3}{4}g_w^2 + \frac{1}{4}g_e^2, \tag{39}$$

$$B_2 = \frac{4}{3}g_s^2 - \frac{1}{4}g_w^2 + \frac{1}{4}g_e^2, \tag{40}$$

$$B_3 = \frac{3}{4}g_w^2 - \frac{1}{4}g_e^2. \tag{41}$$

It is straight to show that if we take central experimental values for the strong constant at the M_Z scale as $\alpha_s(M_Z) = 0.1184$, the fine-structure constant as $\alpha_e = 7.2973525376 \times 10^{-3}$ and the cosine of the electroweak mixing angle as $\cos\theta_w = M_W/M_Z = 80.399/91.1876 = 0.88168786$ [17], then $g_s = 1.21978$, $g_w = 0.641799$ and $g_e = 0.343457$. Substituting the values of g_s, g_w and g_e and the values for the experimental masses of the electrically charged fermions, given by [17] $m_u = 0.0025$ GeV, $m_d = 0.00495$ GeV, $m_c = 1.27$ GeV, $m_s = 0.101$ GeV, $m_t = 172.0 \pm 2.2$ GeV, $m_b = 4.19$ GeV, $m_e = 0.510998910 \times 10^{-3}$ GeV, $m_\mu = 0.105658367$ GeV, $m_\tau = 1.77682$ GeV, into the expressions (33) and (34), and assuming neutrinos as massless particles, $m_{\nu_e} = m_{\nu_\mu} = m_{\nu_\tau} = 0$, we obtain that theoretical masses of the W and Z electroweak gauge bosons are given by

$$M_{W^\pm}^{th} = 79.9344 \pm 1.0208\, GeV \tag{42}$$

$$M_Z^{th} = 90.6606 \pm 1.1587\, GeV. \tag{43}$$

These theoretical masses are in agreement with theirs experimental values given by $M_W^{exp} = 80.399 \pm 0.023$ GeV and $M_Z^{exp} = 91.1876 \pm 0.0021$ GeV [17]. Central values for parameters A_1, A_2, A_3 and A_4 in expressions (33) and (34) are $A_1 = 1.32427 \times 10^{-5}$, $A_2 = 15478$, $A_3 = 34.0137$ and $A_4 = 0$. We observe that A_2 is very large respect to A_3 and A_1. Taking into account the definition of parameter A_2 given by (36) we can conclude that masses of electroweak gauge bosons coming specially from top quark mass m_t and strong running coupling constant g_s. Notwithstanding neutrino masses are not known, direct experimental results show that neutrino masses are of order 1 eV [17], and cosmological interpretations of five-year WMAP observations find a limit on the total mass of neutrinos of $\Sigma m_\nu < 0.6$ eV (95% CL) [18]. These results assure us that values of left-handed lepton chemical potentials obtained of taking neutrinos to be massless will change a little if we take true small neutrinos masses.

4. Some Consequences of this Approach

We note that expressions (33) and (34) establish a very close relationship among twelve fermion masses and three interaction running coupling constants with masses of W and Z electroweak gauge bosons. This fact let us obtain some consequences that we are presenting next.

We conclude that expressions (33) and (34) reasons by experimental uncertainties of electroweak gauge boson masses restrict the existence of a new family of fermions in the SMWHS. We can arrive to this conclusion if we suppose the existence of a new fermion family. We represent the two new leptons as ν_n and l_n, the two new quarks as u_n and d_n, and the mass of these four fermions as m_{ν_n}, m_{l_n}, m_{u_n} and m_{d_n}, respectively. We hope that these fermion masses must be heavier than the ones of the third family. These masses could satisfy: (i) The non-hierarchy condition given by $m_{\nu_n} \sim m_{l_n}$ and $m_{u_n} \sim m_{d_n}$; (ii) the hierarchy condition expressed by $m_{\nu_n} \ll m_{l_n}$ and $m_{u_n} \ll m_{d_n}$. From the first condition, expressions (33) and (34) are modified by the inclusion of terms which are proportional to $m^2_{\nu_n} + m^2_{l_n}$ and $m^2_{u_n} + m^2_{d_n}$. From the second condition, these expressions are modified by terms which are proportional to $m^2_{\nu_n} - m^2_{l_n}$ and $m^2_{u_n} - m^2_{d_n}$. Both cases are strongly suppressed by experimental uncertainties for electroweak gauge boson masses. On this way, our approach establishes a strong restriction for possible existence of the fourth fermion family in the SMWHS.

We obtain also a prediction for top quark mass starting from the expression (34). Using central experimental values for Z and W electroweak gauge boson masses and uncertainties for running coupling constants and for fermion masses, and assuming neutrinos as massless particles, we predict from (34) that top quark mass is $m_t^{th} = 173.0015 \pm 0.6760$ GeV. This theoretical value is in agreement with the experimental value for top quark mass given by [17] $m_t^{exp} = 172.0 \pm 2.2$ GeV.

If we write (38) as

$$A_4 = \frac{(3 + g_e^2/g_w^2)(\Sigma m_\nu^2)}{B_3}, \tag{44}$$

from (34) we obtain that for the summing of squares of neutrino masses Σm_ν^2 can be written as

$$\Sigma m_\nu^2 = \left[A_1 + A_2 + A_3 - \frac{M^2_{Z_{min}}}{g_e^2 + g_w^2} \right] \frac{B_3}{3 + g_e^2/g_w^2}, \tag{45}$$

where $M_{Z_{min}}$ is the smallest experimental value of Z mass given by $M_{Z_{min}} = 91.1855$ GeV. Using $m_t = 173.0015$ GeV and central experimental values for fermion masses and running coupling constants that we have used in section 3, we obtain that $\Sigma m_\nu^2 = 0.06213$ GeV^2. This approach for mass generation predicts that left-handed neutrinos are massive, but this can not predict about the values for neutrino masses due to that fermionic chemical potentials are free parameters. However we find a highest limit for the summing of squares of neutrino masses given by $\Sigma m_\nu^2 < 0.06213$ GeV^2

Conclusions

We have presented an approach of mass generation for Standard Model particles in which we have extracted some generic features of the Higgs mechanism that do not depend on its interpretation in terms of a Higgs field. On this approach the physical vacuum has been assumed to be a medium at zero temperature which is formed by fermions and antifermions interacting among themselves by exchanging gauge bosons. The fundamental effective model describing the dynamics of this physical vacuum is the SMWHS. We have assumed that every fermion flavor in physical vacuum has associated a chemical potential μ_f in such a way that there is an excess of antifermions over fermions. This fact implies that physical vacuum can be understood as a virtual medium having an antimatter finite density.

Fermion masses are calculated starting from fermion self-energy which represents fundamental interactions of a fermion with the physical vacuum. The gauge boson masses are calculated from the charge fluctuations of physical vacuum which are described by a vacuum polarization tensor. Using this approach for particle mass generation we have generated masses for the electroweak gauge bosons in agreement with their experimental values.

A further result of this approach is that left-handed neutrinos are massive due to that they have weak charge. Additionally our approach has established a strong restriction to the existence of a new fermion family in the SMWHS. We have also predicted that top quark mass is $m_t^{th} = 173.0015 \pm 0.6760$ GeV. Finally we have obtained the highest limit for the summing of squares of neutrino masses given by $\Sigma m_\nu^2 < 0.06213$ GeV^2

Acknowledgments

We thank Vicerrectoria de Investigaciones of Universidad Nacional de Colombia by the financial support received through the research grant "Teoría de Campos Cuánticos aplicada a sistemas de la Física de Partículas, de la Física de la Materia Condensada y a la descripción de propiedades del grafeno". C. Quimbay thanks to Rafael Hurtado, Rodolfo Díaz and Antonio Sánchez for stimulating discussions.

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