

# An electroweak model without Higgs particle

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[Abstract] In this paper, applying general gauge field theory, we will construct an electroweak model. In this new electroweak model, Higgs mechanism is not used, so no Higgs particle exists in the model. In order to keep the masses of intermediate gauge bosons non-zero, we will introduce two sets of gauge fields. We need a vacuum potential to introduce symmetry breaking and to introduce the masses of all fields. Except for those terms concern of Higgs particle, the fundamental dynamical properties of this model are similar to those of the standard model. And in a proper limit, this model will approximately return to the standard model.

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# 1 Introduction

After Yang and Mills founded non-Abel gauge field theory in 1954 [1], gauge field theory has been extensively applied to elementary particle theory. Now, it is clearly known that four kinds of fundamental interactions, i.e. strong interactions, electromagnetic interactions, weak interactions and gravitation, are all gauge interactions, and they can be described by gauge theory. From theoretical point of view, the requirement of gauge invariant determines the forms of interactions. In other words, the principle of local gauge invariant plays a fundamental role in particles' interaction theory.

But for Yang-Mills gauge theory, if a system has strict local gauge symmetry, the masses of gauge fields must be zero. But physicists found that the masses of intermediate gauge bosons are very large in the forties [2]. After introducing the concept of spontaneously symmetry breaking and Higgs mechanism which make the gauge fields obtain masses, Glashow [3], Weinberg [4] and Salam [5] founded the well-known unified electroweak standard model. The standard model is consonant well with experiment and the intermediate gauge bosons predicted by the standard model have already been found by experiment [6], but the Higgs particle necessitated by the standard model has not been found by experiment until now. Whether Higgs particle exists in nature? If there were no Higgs particle, how should we construct the unified electroweak model?

The general gauge field theory was put forward by Wu recently [7-8]. The main difference between the general gauge field theory and Yang-Mills gauge field theory is that, there exist massive force-transmitting vector fields in the general gauge theory under the precondition that the system has strict local gauge symmetry. This characteristic of the general gauge theory makes it possible for us to directly construct electroweak model without using Higgs mechanism [9]. Because Higgs mechanism is no longer needed in the new electroweak model, there exists no Higgs particle in the new theory. Furthermore, in a proper limit, the new electroweak model will approximately return to the standard model. So, we could anticipate that there will exist no contradictions between the new electroweak model and experiments which we will discuss in details later.

In this paper, using the general gauge field theory, we will construct a new unified electroweak model. First, we will give the lagrangian for electroweak interactions of leptons. In order to introduce symmetry breaking of the model and the masses of all fields, we need a scalar potential which we will name it vacuum potential. The functions of the vacuum potential are similar to those of Higgs scalar field, but vacuum potential has essential differences from Higgs scalar field. After symmetry

breaking, fermions and gauge bosons obtain masses. The electroweak interactions of quarks will also be discussed in this paper. The dynamical characteristics of this new electroweak model are similar to those of the standard model. And in a proper limit, except for those terms concern of Higgs particle, the new electroweak model will approximately return to the standard model. In this new electroweak model, we will introduce two sets of gauge fields. After some field transformations, one set of gauge fields will obtain masses and another set will keep massless. The existence of these massless gauge bosons is an important characteristic of the new model. If electroweak model should be a minimum model, those massless gauge bosons and Higgs particle can not exist in the same theory. But if we do not add the restriction of minimum model to electroweak interactions, those massless gauge bosons and Higgs particle can exist in the same theory. Therefore, the existence of these massless gauge bosons is not enough to say that Higgs particle does not exist in nature for certain. The existence of these massless gauge bosons only means that Higgs particle may not exist in nature. An important prediction of this new electroweak model is that there exists a new long-range force in nature which may have applications in the future. At the end of this paper, we will present some discussions on some fundamental problems of the new electroweak model.

## 2 The lagrangian of the model (leptons)

Up to now, physicists have found that there exist three generations of leptons and quarks in the nature. In this chapter, we will discuss the electroweak interactions of leptons. For the sake of convenience, let's  $e$  represent leptons  $e, \mu$  or  $\tau$ , and  $\nu$  represent the corresponding neutrinos  $\nu_e, \nu_\mu$  or  $\nu_\tau$ . According to the standard model,  $e$  and  $\nu$  form left-hand doublet  $\psi_L$  which has  $SU(2)_L$  symmetry and right-hand singlet  $e_R$ . Neutrinos have no right-hand singlets. The definitions of these states are:

$$\psi_L = \begin{pmatrix} \nu \\ e \end{pmatrix}_L, \quad y = -1 \quad (2.1)$$

$$e_R, \quad y = -2, \quad (2.2)$$

where  $y$  represents the quantum number of weak hypercharge  $Y$ .

The symmetry of the theory is supposed to be the group  $SU(2)_L \times U(1)_Y$ . The generators of  $SU(2)_L$  are denoted as  $T_i^L = \tau_i/2$  ( $\tau_i$  are Pauli matrices), and the generator of  $U(1)_Y$  group is denoted as  $Y$ . The electric charge of a particle is determined by Gell- Mann-Nishijima rule:

$$Q = T_3^L + \frac{Y}{2}. \quad (2.3)$$

Four gauge fields are needed in the new electroweak theory. They are two non-Abel gauge fields  $F_{1\mu}$  and  $F_{2\mu}$  corresponding to the  $SU(2)_L$  symmetry and two Abelian gauge fields  $B_{1\mu}$  and  $B_{2\mu}$  corresponding to the  $U(1)_Y$  symmetry. Two  $SU(2)_L$  gauge fields  $F_{1\mu}$  and  $F_{2\mu}$  can be expanded as:

$$F_{m\mu} = F_{m\mu}^i \frac{\tau_i}{2}, \quad (m = 1, 2) \quad (2.4)$$

where  $F_{m\mu}^i$  ( $i = 1, 2, 3$ ) are component fields. Corresponding to four gauge fields, we will introduce four gauge covariant derivatives:

$$D_{1\mu} = \partial_\mu - igF_{1\mu} \quad (2.5)$$

$$D_{2\mu} = \partial_\mu + ig\text{tg}\alpha F_{2\mu} \quad (2.6)$$

$$D_{3\mu} = \partial_\mu - ig'B_{1\mu} \frac{Y}{2} \quad (2.7)$$

$$D_{4\mu} = \partial_\mu + ig'\text{tg}\alpha B_{2\mu} \frac{Y}{2}, \quad (2.8)$$

where  $\alpha$  is a dimensionless constant. The strengths of four gauge fields are respectively defined as:

$$F_{1\mu\nu} = \partial_\mu F_{1\nu} - \partial_\nu F_{1\mu} - ig[F_{1\mu}, F_{1\nu}], \quad (2.9)$$

$$F_{2\mu\nu} = \partial_\mu F_{2\nu} - \partial_\nu F_{2\mu} + ig\text{tg}\alpha[F_{2\mu}, F_{2\nu}], \quad (2.10)$$

$$B_{m\mu\nu} = \partial_\mu B_{m\nu} - \partial_\nu B_{m\mu}, \quad (m = 1, 2). \quad (2.11)$$

Field strengths  $F_{1\mu\nu}$  and  $F_{2\mu\nu}$  can be expressed as linear combinations of generators. That is:

$$F_{m\mu\nu} = F_{m\mu\nu}^i \frac{\tau_i}{2}, \quad (m = 1, 2) \quad (2.12)$$

where  $F_{m\mu\nu}^i$  are component field strengths whose expressions are:

$$F_{1\mu\nu}^i = \partial_\mu F_{1\nu}^i - \partial_\nu F_{1\mu}^i + g\epsilon_{ijk} F_{1\mu}^j F_{1\nu}^k \quad (2.13)$$

$$F_{2\mu\nu}^i = \partial_\mu F_{2\nu}^i - \partial_\nu F_{2\mu}^i - g\text{tg}\alpha \epsilon_{ijk} F_{2\mu}^j F_{2\nu}^k \quad (2.14)$$

In order to introduce symmetry breaking, we will introduce a scalar potential  $v$  which we name it vacuum potential for the moment. It has mass dimension. It has no kinematic energy term in the lagrangian. So, it has no dynamical degree of freedom. The coupling between vacuum potential and matter fields can be regarded as a kind of interactions between vacuum and matter fields. Because every Fock space or every symmetry space has its own vacuum, we could select a vacuum potential

for every particle or every symmetry. In this case, the ordinary mass term in the lagrangian can be rewritten as:

$$-\frac{1}{2}v^\dagger\phi(x)\phi(x)v \quad , \quad -\bar{\psi}(x)v\psi(x) \quad (2.15)$$

Because vacuum potential has no dynamical degree of freedom, it is hard to change its value. In the real physical world which is in a special phase of vacuum, its value in space- time is even. In other words,  $v$  is always a constant in our world. Vacuum in different space has different value. For  $U(1)$  case, eq(2.15) changes into:

$$-\frac{m^2}{2}\phi(x)\phi(x) \quad , \quad -m\bar{\psi}(x)\psi(x), \quad (2.16)$$

where  $m$  is the value of  $v$ . In the electroweak model, when  $v$  has definite value, the symmetry of the model will be broken, and quarks, leptons and gauge bosons will obtain masses.

The lagrangian density of the model is :

$$\mathcal{L} = \mathcal{L}_l + \mathcal{L}_g + \mathcal{L}_{v-l}, \quad (2.17)$$

where  $\mathcal{L}_l, \mathcal{L}_g$  and  $\mathcal{L}_{v-l}$  are the lagrangian density for leptons, lagrangian density for gauge fields and interaction lagrangian between vacuum potential and leptons respectively. Their definitions respectively are:

$$\mathcal{L}_l = -\bar{\psi}_L\gamma^\mu(\partial_\mu + \frac{i}{2}g'B_{1\mu} - igF_{1\mu})\psi_L - \bar{e}_R\gamma^\mu(\partial_\mu + ig'B_{1\mu})e_R \quad (2.18)$$

$$\begin{aligned} \mathcal{L}_g = & -\frac{1}{4}F_1^{i\mu\nu}F_{1\mu\nu}^i - \frac{1}{4}F_2^{i\mu\nu}F_{2\mu\nu}^i - \frac{1}{4}B_1^{\mu\nu}B_{1\mu\nu} - \frac{1}{4}B_2^{\mu\nu}B_{2\mu\nu} \\ & -v^\dagger [\cos\theta_W(\cos\alpha F_1^\mu + \sin\alpha F_2^\mu) - \sin\theta_W(\cos\alpha B_1^\mu + \sin\alpha B_2^\mu)] \\ & \cdot [\cos\theta_W(\cos\alpha F_{1\mu} + \sin\alpha F_{2\mu}) - \sin\theta_W(\cos\alpha B_{1\mu} + \sin\alpha B_{2\mu})] v \end{aligned} \quad (2.19)$$

$$\mathcal{L}_{v-l} = -f(\bar{e}_R v^\dagger \psi_L + \bar{\psi}_L v e_R), \quad (2.20)$$

where  $f$  is a dimensionless parameter ,  $\alpha$  is a constant,  $g, g'$  are coupling constants and  $\theta_W$  are Weinberg angle. The relation of coupling constants and Weinberg angle is given by:

$$\text{tg}\theta_W = g'/g \quad (2.21)$$

We have noticed that  $\mathcal{L}_l$  and  $\mathcal{L}_{v-l}$  are completely the same as the corresponding parts of the standard model. And there is no kinematic energy term for the vacuum potential  $v$  in the lagrangian. So  $v$  is not a dynamical field.

Now, let's consider the symmetry of the model. The local  $SU(2)_L$  gauge transformations of fields are:

$$\psi_L \longrightarrow U\psi_L \quad (2.22)$$

$$e_R \longrightarrow e_R \quad (2.23)$$

$$F_{1\mu} \longrightarrow UF_{1\mu}U^\dagger - \frac{1}{ig}U\partial_\mu U^\dagger \quad (2.24)$$

$$F_{2\mu} \longrightarrow UF_{2\mu}U^\dagger + \frac{1}{igtg\alpha}U\partial_\mu U^\dagger \quad (2.25)$$

$$B_{i\mu} \longrightarrow B_{i\mu} \quad (i = 1, 2) \quad (2.26)$$

$$v \longrightarrow Uv, \quad (2.27)$$

where  $U$  is the operator of local  $SU(2)_L$  gauge transformation. The local  $U(1)_Y$  gauge transformations of fields are:

$$\psi_L \longrightarrow e^{i\beta(x)}\psi_L \quad (2.28)$$

$$e_R \longrightarrow e^{2i\beta(x)}e_R \quad (2.29)$$

$$F_{i\mu} \longrightarrow F_{i\mu} \quad (i = 1, 2) \quad (2.30)$$

$$B_{1\mu} \longrightarrow B_{1\mu} - \frac{2}{g'}\partial_\mu\beta(x) \quad (2.31)$$

$$B_{2\mu} \longrightarrow B_{2\mu} + \frac{2}{g'tg\alpha}\partial_\mu\beta(x) \quad (2.32)$$

$$v \longrightarrow e^{-i\beta(x)}v. \quad (2.33)$$

It is easy to prove that the lagrangian defined by eq(2.17-20) is invariant under the above local  $SU(2)_L \times U(1)_Y$  gauge transformations, so the lagrangian has strict local  $SU(2)_L \times U(1)_Y$  gauge symmetry.

In the above lagrangian, there are two sets of gauge fields. The second set of gauge fields is the compensatory fields of the first set. In other words, the gauge transformations of the first set of gauge fields are determined by the gauge transformation of matter fields, and the gauge transformations of the second set of gauge fields are determined by the transformation the first set of gauge fields. So, there is no restriction on gauge transformations and the model has the maximal local  $SU(2)_L \times U(1)_Y$  gauge symmetry. In the same time, we should notice that  $F_{1\mu}$ ,  $F_{2\mu}$ ,  $B_{1\mu}$  and  $B_{2\mu}$  are all standard gauge fields. In the present case, we do not let gauge fields  $F_{2\mu}$  and  $B_{2\mu}$  interact with matter fields. According to reference [8 ], after introducing a new parameter, we could let both two sets of gauge fields interact directly with matter fields. But we do not do so in this paper so as to keep gauge fields minimal couple to matter fields in the original lagrangian.

### 3 Symmetry breaking and masses of particles

We have already said that  $v$  represents the influence of vacuum above. Although in the original lagrangian density,  $v$  has the degree of freedom of gauge transformation, in our real physical world, the state of vacuum can not be varied freely and the properties of vacuum are rather stable, it has no gauge transformation degree of freedom. In the local inertial coordinate system, vacuum is invariant under space-time translation. So  $v$  is well-distributed, it is a constant. Suppose that  $v$  has the following value

$$v = \begin{pmatrix} v_1 \\ v_2 \end{pmatrix}, \quad (3.1)$$

where  $v_1$  and  $v_2$  satisfy the following relation:

$$v_1^2 + v_2^2 = \mu^2/2, \quad (3.2)$$

where  $\mu$  is a constant with mass dimension. Please note that eq(3.1) is the most general form of two-component vector constant  $v$ . But it is not the correct form of the vacuum of our world. So we make a global  $SU(2)_L$  gauge transformation so as to make  $v$  change into the following form

$$v = \begin{pmatrix} 0 \\ \mu/\sqrt{2} \end{pmatrix}. \quad (3.3)$$

Because the lagrangian has global  $SU(2)_L \times U(1)_Y$  gauge symmetry, its form keeps unchanged under the above global transformation. It is known that the properties of vacuum affect the dynamical properties of our physical world. In present case, different forms of vacuum potential  $v$  will give different forms of lagrangian after symmetry breaking. In our real physical world, the electroweak vacuum potential is given by eq(3.3). We could understand eq(3.3) from another point of view. Although in the original lagrangian vacuum has very high symmetry, in our real physical world, it does not have so high symmetry. The vacuum of our real world is stable, so it is in a special gauge which is determined by eq(3.3). We adopt eq(3.3) means that we have select a special gauge. So, eq(3.3) is the gauge condition of our world. When we select a special gauge, the symmetry of the model is broken at the same time. So, in this point of view, symmetry breaking is originated from gauge fixing of the vacuum.

After symmetry breaking, gauge fields  $F_{1\mu}$ ,  $F_{2\mu}$ ,  $B_{1\mu}$  and  $B_{2\mu}$  are not eigenvectors of mass matrix, so they don't correspond to the fields of particles in the real physical world. In order to obtain eigenvectors of mass matrix, we will make the following two sets of transformations of fields. The first set of transformations are:

$$W_\mu = \cos\alpha F_{1\mu} + \sin\alpha F_{2\mu} \quad (3.4)$$

$$W_{2\mu} = -\sin\alpha F_{1\mu} + \cos\alpha F_{2\mu} \quad (3.5)$$

$$C_{1\mu} = \cos\alpha B_{1\mu} + \sin\alpha B_{2\mu} \quad (3.6)$$

$$C_{2\mu} = -\sin\alpha B_{1\mu} + \cos\alpha B_{2\mu}. \quad (3.7)$$

The second set of transformations are:

$$Z_\mu = \sin\theta_W C_{1\mu} - \cos\theta_W W_\mu^3 \quad (3.8)$$

$$A_\mu = \cos\theta_W C_{1\mu} + \sin\theta_W W_\mu^3 \quad (3.9)$$

$$Z_{2\mu} = \sin\theta_W C_{2\mu} - \cos\theta_W W_{2\mu}^3 \quad (3.10)$$

$$A_{2\mu} = \cos\theta_W C_{2\mu} + \sin\theta_W W_{2\mu}^3. \quad (3.11)$$

The first set of transformations are the standard transformations discussed in references [7] and [8]. The second set of transformations are the standard transformations used in the standard model. After these two sets of field transformations, all terms of two-body coupling of gauge fields disappear from the lagrangian.

As we have mentioned at the end of chapter two, fields  $F_{1\mu}$ ,  $F_{2\mu}$ ,  $B_{1\mu}$  and  $B_{2\mu}$  are all standard gauge fields. Although, after the first set of field transformation, the gauge transformations of  $W_\mu$  and  $C_{1\mu}$  are not in the standard forms of gauge transformation, for the sake of convenience, we call them general gauge fields, or simply call them gauge fields. It is obvious that  $W_\mu$  and  $C_{1\mu}$  are not ordinary vector fields, because they are "made from" gauge fields (according to eq(3.4) and eq(3.6)) and they transmit interactions between matter fields. Therefore, it is not suitable to call them ordinary vector fields or to regard them as ordinary matter fields. We call them general gauge fields for the present. Similarly, we call  $W_\mu^\pm$ ,  $Z_\mu$  and  $A_\mu$  general gauge fields.

After all these transformations, the lagrangian densities of the model change into:

$$\begin{aligned} \mathcal{L}_l + \mathcal{L}_{v-l} = & -\bar{e}(\gamma^\mu \partial_\mu + \frac{1}{\sqrt{2}} f \mu) e - \bar{\nu}_L \gamma^\mu \partial_\mu \nu_L \\ & + \frac{1}{2} \sqrt{g^2 + g'^2} \sin 2\theta_W j_\mu^{em} (\cos\alpha A^\mu - \sin\alpha A_2^\mu) \\ & - \sqrt{g^2 + g'^2} j_\mu^z (\cos\alpha Z^\mu - \sin\alpha Z_2^\mu) \\ & + \frac{\sqrt{2}}{2} i g \bar{\nu}_L \gamma^\mu e_L (\cos\alpha W_\mu^+ - \sin\alpha W_{2\mu}^+) \\ & + \frac{\sqrt{2}}{2} i g \bar{e}_L \gamma^\mu \nu_L (\cos\alpha W_\mu^- - \sin\alpha W_{2\mu}^-) \end{aligned} \quad (3.12)$$

$$\begin{aligned} \mathcal{L}_g = & -\frac{1}{2} W_0^{+\mu\nu} W_{0\mu\nu}^- - \frac{1}{4} Z^{\mu\nu} Z_{\mu\nu} - \frac{1}{4} A^{\mu\nu} A_{\mu\nu} \\ & - \frac{1}{2} W_{20}^{+\mu\nu} W_{20\mu\nu}^- - \frac{1}{4} Z_2^{\mu\nu} Z_{2\mu\nu} - \frac{1}{4} A_2^{\mu\nu} A_{2\mu\nu} , \\ & - \frac{\mu^2}{2} Z^\mu Z_\mu - \mu^2 \cos^2 \theta_W W^{+\mu} W_\mu^- + \mathcal{L}_{gI} \end{aligned} \quad (3.13)$$



where  $\mathcal{L}_{gI}$  only contains interaction terms of gauge fields, and

$$W_{m\mu}^{\pm} = \frac{1}{\sqrt{2}}(W_{m\mu}^1 \mp iW_{m\mu}^2) \quad (m = 1, 2, W_{1\mu} \equiv W_{\mu}). \quad (3.14)$$

In the above lagrangian, the field strengths of gauge fields are defined as:

$$W_{m0\mu\nu}^{\pm} = \partial_{\mu}W_{m\nu}^{\pm} - \partial_{\nu}W_{m\mu}^{\pm} \quad (m = 1, 2, W_{1\mu}^{\pm} \equiv W_{\mu}^{\pm}), \quad (3.15)$$

$$Z_{m\mu\nu} = \partial_{\mu}Z_{m\nu} - \partial_{\nu}Z_{m\mu} \quad (m = 1, 2, Z_{1\mu} \equiv Z_{\mu}), \quad (3.16)$$

$$A_{m\mu\nu} = \partial_{\mu}A_{m\nu} - \partial_{\nu}A_{m\mu} \quad (m = 1, 2, A_{1\mu} \equiv A_{\mu}). \quad (3.17)$$

The currents in the above lagrangian are defined as:

$$j_{\mu}^{em} = -i\bar{e}\gamma_{\mu}e \quad (3.18)$$

$$j_{\mu}^Z = j_{\mu}^3 - \sin^2\theta_W j_{\mu}^{em} = i\bar{\psi}_L\gamma_{\mu}\frac{\tau^3}{2}\psi_L - \sin^2\theta_W j_{\mu}^{em}. \quad (3.19)$$

From the above lagrangian, we could see that the mass of fermion  $e$  is  $\frac{1}{\sqrt{2}}f\mu$ , the mass of neutrino is zero, the masses of charged intermediate gauge bosons  $W^{\pm}$  are  $\mu\cos\theta_W$ , the mass of neutral intermediate gauge boson  $Z$  is  $\mu = \frac{m_W}{\cos\theta_W}$  and all other gauge fields are massless. That is

$$m_e = \frac{1}{\sqrt{2}}f\mu \quad , \quad m_{\nu} = 0 \quad (3.20)$$

$$m_W = \mu\cos\theta_W \quad , \quad m_Z = \mu = \frac{m_W}{\cos\theta_W} \quad (3.21)$$

$$m_A = m_{A2} = m_{W2} = m_{Z2} = 0 \quad (3.22)$$

It is easy to see that, in this model, the expressions of the masses of fermions and intermediate gauge bosons are the same as those in the standard model.

## 4 Compare with the Standard Model

We have known that the standard model is a successful model in describing electroweak interactions when the energy of the system is not very high. If the new electroweak model is also a successful model in describing high energy electroweak interactions, it should be able to return to the standard model in a limit. The lagrangian of the new electroweak model discussed above is quite different in form

from that of the standard model. And all these differences concern of the parameter  $\alpha$  and Higgs field. Parameter  $\alpha$  is a free parameter whose value is not determined at present. If we let the value of  $\alpha$  vary, then in a proper limit, the model discussed above will approximately return to the standard model. Now, let's discuss the standard model limit of the new electroweak model. Suppose that parameter  $\alpha$  is much smaller than 1,

$$\alpha \ll 1, \quad (4.1)$$

then in the leading term approximation,

$$\cos\alpha \approx 1 \quad , \quad \sin\alpha \approx 0. \quad (4.2)$$

In this case, the lagrangian density for fermions becomes:

$$\begin{aligned} \mathcal{L}_l + \mathcal{L}_{v-l} = & -\bar{e}(\gamma^\mu \partial_\mu + \frac{1}{\sqrt{2}}f\mu)e - \bar{\nu}_L \gamma^\mu \partial_\mu \nu_L \\ & + e j_\mu^{em} A^\mu - \sqrt{g^2 + g'^2} j_\mu^z Z^\mu \\ & + \frac{\sqrt{2}}{2} i g \bar{\nu}_L \gamma^\mu e_L W_\mu^+ + \frac{\sqrt{2}}{2} i g \bar{e}_L \gamma^\mu \nu_L W_\mu^- \end{aligned} \quad (4.3)$$

where

$$e = \frac{gg'}{\sqrt{g^2 + g'^2}} \quad (4.4)$$

is the coupling constant of electromagnetic interactions. From eq(4.3), we see  $\mathcal{L}_l + \mathcal{L}_{v-l}$  is the same as the corresponding lagrangian density in the standard model. Besides, in this approximation, the form of  $\mathcal{L}_{gI}$  is simplified and the terms in  $\mathcal{L}_g$  other than  $\mathcal{L}_{gI}$  do not change. Therefore, in this approximation, except for the terms concern Higgs particle, the lagrangian of the model discussed in this paper is almost the same as that of the standard model: they have the same mass relation of the intermediate gauge bosons, the same charged currents and neutral current, the same electromagnetic current, the same coupling constant of the electromagnetic interactions, the same effective coupling constant of weak interactions  $\dots$  etc.. On the other hand, we must see that there are two fundamental differences between the new electroweak model and the standard model: 1) there is no Higgs particle in the new electroweak model, so there are no interaction terms between Higgs particle and leptons, quarks or gauge bosons; 2) compare with the standard model, we have introduced two sets of gauge fields in the new electroweak model. These new gauge bosons are all massless. In the limit  $\alpha \rightarrow 0$ , the coupling between massless gauge bosons and quarks or leptons will also go to zero. Because  $\alpha$  is very small (which we will discussed later), the influences of these massless gauge bosons to the course of electroweak interactions will be small too. No differences between these two electroweak theories are detected by experiments. Therefore, we could anticipate that, if parameter  $\alpha$  is small, two electroweak theories will give similar results in describing low energy electroweak interactions of quarks and leptons, and there will exist

no contradictions between new electroweak model and experiments on electroweak interactions.

In the present model, we have introduced eight kinds of gauge bosons, they are:  $W^\pm$ ,  $Z$ ,  $A$ ,  $W_2^\pm$ ,  $Z_2$  and  $A_2$ . Those four kinds of gauge bosons in front have already been introduced in the standard model, others are introduced by the present model. So, in the present theory, there are two kinds of charged massive gauge bosons, one kind of neutral massive gauge boson, three kinds of neutral massless gauge bosons and two kinds of charged massless gauge bosons.

There are two different kinds of intermediate gauge bosons which couple to matter fields in different manners. The coupling constants between leptons and massive charged intermediate gauge bosons or massless charged intermediate gauge bosons respectively are:

$$g \cos\alpha \quad , \quad g \sin\alpha \quad (4.5)$$

There are also two different coupling constants between leptons and massive neutral intermediate gauge boson or massless neutral intermediate gauge bosons, they are

$$\sqrt{g^2 + g'^2} \cos\alpha \quad , \quad \sqrt{g^2 + g'^2} \sin\alpha \quad (4.6)$$

The effective coupling constant of Fermi weak interactions caused by massive intermediate gauge bosons is

$$\frac{G}{\sqrt{2}} = \frac{g^2}{8m_W^2} \cos^2\alpha. \quad (4.7)$$

When the parameter  $\alpha$  is very small, the above relation will return to the well-known relation in the standard model. That means that, in the low-energy phenomena, the new electroweak theory will give a correct description on Fermi weak interactions.

There exist two different kinds of electromagnetic fields  $A_\mu$  and  $A_{2\mu}$ , correspondingly, there exist two different kinds coupling constants of electromagnetic interactions. They respectively are:

$$e_1 = \frac{gg'}{\sqrt{g^2 + g'^2}} \cos\alpha = e \cos\alpha \quad (4.8)$$

$$e_1 = \frac{gg'}{\sqrt{g^2 + g'^2}} \sin\alpha = e \sin\alpha \quad (4.9)$$

The electromagnetic field exist in nature should be a mixture of the two different kinds electromagnetic fields  $A_\mu$  and  $A_{2\mu}$ . In other words, the electromagnetic interactions in nature should be transmitted by both  $A_\mu$  and  $A_{2\mu}$ . The effective coupling

constant of electromagnetic interactions should be:

$$e^2 = e_1^2 + e_2^2 \quad , \quad e = \frac{gg'}{\sqrt{g^2 + g'^2}} \quad (4.10)$$

So, the effective coupling constant of electromagnetic interactions is the same as the coupling constant of electromagnetic interactions in the standard model. Furthermore, the value of the parameter  $\alpha$  does not affect the value of effective coupling constant of electromagnetic interactions. Therefore, although we have introduced two different kinds of electromagnetic fields, the law for electromagnetic interactions will not be changed. And, no matter how much is the parameter  $\alpha$ , two electroweak theories will give the same results in describing pure electromagnetic interaction course.

There are three kinds of massless neutral gauge bosons in the new theory. They are  $Z_2$ ,  $A$  and  $A_2$ . They are all stable particles and interact with quarks or leptons. In other words, they have similar interaction properties. The most important phenomenological difference between photon and  $Z_2$  particle is that  $Z_2$  particle interacts with neutrino but photon does not interact with neutrino. But this difference is hard to detect in the experiment. In other words, if there is  $Z_2$  particle mixed in photon, it is hard to distinguish them. If physicists found that photon take part in weak interactions much stronger than expected, that means that there is likely  $Z_2$  particle mixed in photon. Some more discussions on them will be presented in the final chapter.

It is known that there are two kinds of long-range force fields: gravitation field and electromagnetic field. If  $Z_2$  particle exists in nature, there will be a new kind of long-range force field transmitted by massless  $Z_2$  particle. Some more discussions on this problem can be found at the end of this paper.

In a word, when parameter  $\alpha$  is small enough, the new electroweak model will approximately return to the standard model. Because the theoretical predictions of the standard model coincide well with experimental results, we could believe that the parameter  $\alpha$  will be very small. But, even if  $\alpha \rightarrow 0$ , the new electroweak model can not completely return to the standard model, because there exists no Higgs particle in the new electroweak model and there exist no  $W_2^\pm$  and  $Z_2$  particles in the standard model. Up to now, no differences between these two electroweak models are detected by experiments, so, at present, it is hard to say that which model is the correct model in describing electroweak interactions. Some more discussions on these two models will be presented at the end of this paper.

## 5 Electroweak interactions of quarks

Now, let's discuss the electroweak interactions of quarks. It is known that, up to now, there are three generations of quarks which have six different flavours. Quarks take part in strong interactions, electromagnetic interactions and weak interactions. In this section, we will use the general gauge field theory [7-8] to construct the electroweak model for quarks.

According to the standard model, there exists mixing between three different kinds of quarks  $d$ ,  $s$  and  $b$  [10]. Define:

$$\begin{pmatrix} d_\theta \\ s_\theta \\ b_\theta \end{pmatrix} = K \begin{pmatrix} d \\ s \\ b \end{pmatrix}, \quad (5.1)$$

where  $K$  is the Kabayashi-Maskawa mixing matrix whose general form is:

$$K = \begin{pmatrix} c_1 & s_1 c_3 & s_1 s_3 \\ -s_1 c_2 & c_1 c_2 c_3 - s_2 s_3 e^{i\delta} & c_1 c_2 s_3 + s_2 c_3 e^{i\delta} \\ s_1 s_2 & -c_1 s_2 c_3 - c_2 s_3 e^{i\delta} & -c_1 s_2 s_3 + c_2 c_3 e^{i\delta} \end{pmatrix} \quad (5.2)$$

where

$$c_i = \cos\theta_i, \quad s_i = \sin\theta_i \quad (i = 1, 2, 3) \quad (5.3)$$

and  $\theta_i$  are generalized Cabibbo angles.

According to the standard model, quarks form left-hand doublets and right-hand singlets. Denote:

$$q_L^{(1)} = \begin{pmatrix} u_L \\ d_{\theta L} \end{pmatrix}, \quad q_L^{(2)} = \begin{pmatrix} c_L \\ s_{\theta L} \end{pmatrix}, \quad q_L^{(3)} = \begin{pmatrix} t_L \\ b_{\theta L} \end{pmatrix} \quad (5.4)$$

$$\begin{aligned} U_R^{(1)} &= u_R & U_R^{(2)} &= c_R & U_R^{(3)} &= t_R \\ D_{\theta R}^{(1)} &= d_{\theta R} & D_{\theta R}^{(2)} &= s_{\theta R} & D_{\theta R}^{(3)} &= b_{\theta R} \end{aligned} \quad (5.5)$$

It is known that left-hand doublets have weak isospin  $\frac{1}{2}$  and weak hypercharge  $\frac{1}{3}$ , right-hand singlets have no weak isospin,  $U_R^{(j)}$ s have weak hypercharge  $\frac{4}{3}$  and  $D_{\theta R}^{(j)}$ s have weak hypercharge  $-\frac{2}{3}$ .

The lagrangian of the model consists of three parts:

$$\mathcal{L} = \mathcal{L}_q + \mathcal{L}_g + \mathcal{L}_{v-q} \quad (5.6)$$

where  $\mathcal{L}_q$  is the lagrangian density of quark fields,  $\mathcal{L}_g$  is the lagrangian density of gauge fields which is given by eq.(2.19) and  $\mathcal{L}_{v-q}$  contains the interaction terms

among quarks fields and vacuum potential. The lagrangian density of quark fields is:

$$\begin{aligned} \mathcal{L}_q = & -\sum_{j=1}^3 \bar{q}_L^{(j)} \gamma^\mu (\partial_\mu - igF_{1\mu} - \frac{i}{6}g'B_{1\mu}) q_L^{(j)} - \sum_{j=1}^3 \bar{U}_R^{(j)} \gamma^\mu (\partial_\mu - i\frac{2}{3}g'B_{1\mu}) U_R^{(j)} \\ & - \sum_{j=1}^3 \bar{D}_{\theta R}^{(j)} \gamma^\mu (\partial_\mu + i\frac{1}{3}g'B_{1\mu}) D_{\theta R}^{(j)} \end{aligned} \quad (5.7)$$

And the interaction lagrangian density of quark fields and vacuum potential is:

$$\mathcal{L}_{v-q} = -\sum_{j=1}^3 (f^{(j)} \bar{q}_L^{(j)} \bar{v} U_R^{(j)} + f^{(j)*} \bar{U}_R^{(j)} \bar{v}^\dagger q_L^{(j)}) - \sum_{j,k=1}^3 (f^{(jk)} \bar{q}_L^{(j)} v D_{\theta R}^{(k)} + f^{(jk)*} \bar{D}_{\theta R}^{(k)} v^\dagger q_L^{(j)}) \quad (5.8)$$

where

$$\bar{v} = i\sigma_2 v^* = \begin{pmatrix} v_2^\dagger \\ -v_1^\dagger \end{pmatrix} \quad (5.9)$$

The lagrangian density given by eq(5.6-8) is invariant under the following local  $SU(2)_L$  gauge transformation:

$$q_L^{(j)} \longrightarrow U q_L^{(j)} \quad (5.10)$$

$$U_R^{(j)} \longrightarrow U_R^{(j)} \quad (5.11)$$

$$D_{\theta R}^{(j)} \longrightarrow D_{\theta R}^{(j)} \quad (5.12)$$

$$F_{1\mu} \longrightarrow U F_{1\mu} U^\dagger - \frac{1}{ig} U \partial_\mu U^\dagger \quad (5.13)$$

$$F_{2\mu} \longrightarrow U F_{2\mu} U^\dagger + \frac{1}{igtg\alpha} U \partial_\mu U^\dagger \quad (5.14)$$

$$B_{m\mu} \longrightarrow B_{m\mu} \quad (m = 1, 2) \quad (5.15)$$

$$v \longrightarrow U v \quad (5.16)$$

$$\bar{v} \longrightarrow U \bar{v} \quad (5.17)$$

and the following local  $U(1)_Y$  gauge transformations:

$$q_L^{(j)} \longrightarrow e^{-i\beta/3} q_L^{(j)} \quad (5.18)$$

$$U_R^{(j)} \longrightarrow e^{-4i\beta/3} U_R^{(j)} \quad (5.19)$$

$$D_{\theta R}^{(j)} \longrightarrow e^{2i\beta/3} D_{\theta R}^{(j)} \quad (5.20)$$

$$F_{m\mu} \longrightarrow F_{m\mu} \quad (m = 1, 2) \quad (5.21)$$

$$B_{1\mu} \longrightarrow B_{1\mu} - \frac{2}{g'} \partial_\mu \beta \quad (5.22)$$

$$B_{2\mu} \longrightarrow B_{2\mu} + \frac{2}{g'tg\alpha} \partial_\mu \beta \quad (5.23)$$

$$v \longrightarrow e^{-i\beta} v \quad (5.24)$$

$$\bar{v} \longrightarrow e^{i\beta} \bar{v}. \quad (5.25)$$

In other words, the lagrangian density define by eq.(5.6) has strict local  $SU(2)_L \times U(1)_Y$  gauge symmetry.

After symmetry breaking, vacuum potential  $v$  has the form of eq.(3.3). Correspondingly, the form of  $\bar{v}$  is:

$$\bar{v} = \begin{pmatrix} \frac{\mu}{\sqrt{2}} \\ 0 \end{pmatrix}. \quad (5.26)$$

Then, we make a sequence of transformations of gauge fields defined by eq.(3.3-11). After these transformations of gauge fields, the lagrangian density of gauge fields becomes the form given by eq.(3.13). Correspondingly, the lagrangian density of quark fields becomes:

$$\begin{aligned} \mathcal{L}_q = & -\bar{u}\not{\partial}u - \bar{d}\not{\partial}d - \bar{c}\not{\partial}c - \bar{s}\not{\partial}s - \bar{t}\not{\partial}t - \bar{b}\not{\partial}b \\ & + \frac{1}{2}\sqrt{g^2 + g'^2}\sin 2\theta_W j_\mu^{em}(\cos\alpha A^\mu - \sin\alpha A_2^\mu) \\ & - \sqrt{g^2 + g'^2}j_\mu^z(\cos\alpha Z^\mu - \sin\alpha Z_2^\mu) \\ & + \frac{\sqrt{2}}{2}ig(\bar{u}_L\gamma^\mu d_{\theta L} + \bar{c}_L\gamma^\mu s_{\theta L} + \bar{t}_L\gamma^\mu b_{\theta L})(\cos\alpha W_\mu^+ - \sin\alpha W_{2\mu}^+) \\ & + \frac{\sqrt{2}}{2}ig(\bar{d}_{\theta L}\gamma^\mu u_L + \bar{s}_{\theta L}\gamma^\mu c_L + \bar{b}_{\theta L}\gamma^\mu t_L)(\cos\alpha W_\mu^- - \sin\alpha W_{2\mu}^-) \end{aligned} \quad (5.27)$$

In the above equation, currents are defined by the following relations:

$$j_\mu^{em} = i\left(\frac{2}{3}\bar{u}\gamma_\mu u - \frac{1}{3}\bar{d}\gamma_\mu d + \frac{2}{3}\bar{c}\gamma_\mu c - \frac{1}{3}\bar{s}\gamma_\mu s + \frac{2}{3}\bar{t}\gamma_\mu t - \frac{1}{3}\bar{b}\gamma_\mu b\right) \quad (5.28)$$

$$j_\mu^Z = j_\mu^3 - \sin^2\theta_W j_\mu^{em}. \quad (5.29)$$

$$\begin{aligned} j_\mu^3 &= \sum_{j=1}^3 i\bar{q}_L^{(j)}\gamma_\mu \frac{\tau_3}{2}q_L^{(j)} \\ &= \frac{i}{2}(\bar{u}_L\gamma_\mu u_L - \bar{d}_L\gamma_\mu d_L + \bar{c}_L\gamma_\mu c_L - \bar{s}_L\gamma_\mu s_L + \bar{t}_L\gamma_\mu t_L - \bar{b}_L\gamma_\mu b_L) \end{aligned} \quad (5.30)$$

And the lagrangian density for the interactions among quark fields and vacuum potential becomes:

$$\mathcal{L}_{v-q} = -\frac{\mu}{\sqrt{2}} \sum_{j=1}^3 (f^{(j)}\bar{u}_L^{(j)}U_R^{(j)} + f^{(j)*}\bar{U}_R^{(j)}u_L^{(j)}) - \frac{\mu}{\sqrt{2}} \sum_{j,k=1}^3 (f^{(jk)}\bar{d}_{\theta L}^{(j)}D_{\theta R}^{(k)} + f^{(jk)*}\bar{D}_{\theta R}^{(k)}d_{\theta L}^{(j)}) \quad (5.31)$$

Denote

$$F = (f^{(jk)}) \quad (5.32)$$

is a  $3 \times 3$  matrix. In eq(5.8), parameters  $f^{(j)}$  and  $f^{(jk)}$  are selected to satisfy the following requirements:

$$f^{(j)*} = f^{(j)}, \quad f^{(jk)*} = f^{(kj)}. \quad (5.33)$$

So, matrix  $F$  is an Hermit matrix, it could be diagonalized through similarity transformation. In electroweak model, matrix  $F$  is selected to have the following form:

$$F = \frac{\sqrt{2}}{\mu} K M_D K^\dagger \quad (5.34)$$

where  $K$  is the similarity transformation matrix which is defined by eq(5.2) and  $M_D$  is a diagonal matrix whose form is:

$$M_D = \begin{pmatrix} m_d & & \\ & m_s & \\ & & m_b \end{pmatrix}. \quad (5.35)$$

Because  $K$  is a unitary matrix, lagrangian density  $\mathcal{L}_{v-q}$  becomes

$$\mathcal{L}_{v-q} = -m_u \bar{u}u - m_d \bar{d}d - m_c \bar{c}c - m_s \bar{s}s - m_t \bar{t}t - m_b \bar{b}b \quad (5.36)$$

where,

$$m_u = f^{(1)} \mu / \sqrt{2}, \quad m_c = f^{(2)} \mu / \sqrt{2}, \quad m_t = f^{(3)} \mu / \sqrt{2}. \quad (5.37)$$

After all these operations, we could obtain the following result:

$$\begin{aligned} \mathcal{L}_q + \mathcal{L}_{v-q} = & -\bar{u}(\not{\partial} + m_u)u - \bar{c}(\not{\partial} + m_c)c - \bar{t}(\not{\partial} + m_t)t \\ & -\bar{d}(\not{\partial} + m_d)d - \bar{s}(\not{\partial} + m_s)s - \bar{b}(\not{\partial} + m_b)b \\ & + \frac{1}{2} \sqrt{g^2 + g'^2} \sin 2\theta_W j_\mu^{em} (\cos \alpha A^\mu - \sin \alpha A_2^\mu) \\ & - \sqrt{g^2 + g'^2} j_\mu^z (\cos \alpha Z^\mu - \sin \alpha Z_2^\mu) \\ & + \frac{\sqrt{2}}{2} i g (\bar{u}_L \gamma^\mu d_{\theta L} + \bar{c}_L \gamma^\mu s_{\theta L} + \bar{t}_L \gamma^\mu b_{\theta L}) (\cos \alpha W_\mu^+ - \sin \alpha W_{2\mu}^+) \\ & + \frac{\sqrt{2}}{2} i g (\bar{d}_{\theta L} \gamma^\mu u_L + \bar{s}_{\theta L} \gamma^\mu c_L + \bar{b}_{\theta L} \gamma^\mu t_L) (\cos \alpha W_\mu^- - \sin \alpha W_{2\mu}^-) \end{aligned} \quad (5.38)$$

In the limit  $\alpha \rightarrow 0$ , except for those terms concern of Higgs field, the electroweak model for quarks discussed in this chapter will also approximately return to the standard model. The new electroweak model and the standard model have the



same electromagnetic current, the same neutral current, the same charged currents, the same coupling constants for weak and electromagnetic interactions and the same expressions for quark masses. If  $\alpha$  is very small, the coupling between quarks and massless intermediate gauge bosons is also very small. Therefore, the correction cause by massless intermediate gauge bosons will be very small and the effects of interactions between quarks and massless intermediate gauge bosons are hard to be detected by experiments. In a words, except for Higgs particle and interactions between Higgs particle and quarks, the new electroweak model keeps almost all other dynamical properties of the standard model.

## 6 Discussions

The main goal of this paper is to construct an electroweak model in which we avoid using Higgs mechanism and avoid introducing Higgs particle. We know that, up to now, although the energy of accelerated particles has already reached several Tev, experimental physicists don't find any evidence of the existence of Higgs particle. Besides, the mass of Higgs particle predicted by theory has been rising from several Gev to several hundred Gev. This situation gives us an impression that Higgs particle probably doesn't exist in nature. On the other hand, the standard model has obtained tremendous achievement in describing electroweak interactions. So, if Higgs particle does not exist in nature, how to construct an electroweak model, in which Higgs mechanism is not used and the underlying dynamical properties of the new theory are quite similar to those of the standard model, is an important and urgent task for theoretical physicists. Although we don't know whether Higgs particle exists in nature or not, constructing such kind electroweak model is still important theoretically. At least, this model gives us an important result that, without Higgs particle, a correct electroweak theory which coincides with experimental results could also be constructed. In other words, if we could construct such kind electroweak model, it means that Higgs particle is not a necessary part of an acceptable electroweak model. If in the future, physicists have proved that Higgs particle doesn't exist in nature, any attempt to construct an electroweak model without Higgs particle will become more and more important, for the future correct electroweak theory must come from this attempt. Therefore, from whatever point of view, constructing an electroweak model without Higgs particle is interesting and important theoretically.

Although there exists no Higgs particle in the new electroweak model, there exist a vacuum potential and some new particles in the new electroweak model. All these new particles are massless gauge bosons which do not exist in the standard

model. In order to understand the roles of these massless gauge bosons in the new electroweak model, we first discuss the roles of Higgs fields in the standard model. In order to introduce the masses of intermediate gauge bosons, leptons and quarks, we must introduce Higgs scalar fields and Higgs mechanism in the standard model. In the standard model, Higgs fields have the following two important roles: 1) to introduce the masses of intermediate bosons, the masses of quarks and the masses of leptons; 2) to keep the local gauge symmetry of the original lagrangian so as to make the theory renormalizable. If we try to construct a new electroweak model in which Higgs mechanism is not used, we must look for some new fields which could take place the roles of Higgs fields in the standard model. Those new massless gauge fields and vacuum potential are these things we are looking for. (The goal of the introduction of vacuum potential is to introduce symmetry breaking and the masses of leptons, quarks and intermediate gauge bosons. ) In the new electroweak model, we have introduced two sets of gauge fields. One set of gauge fields are the original ones introduced in the standard model. Another set of gauge fields could be regarded as complementary fields of the original gauge fields whose function is to introduce the masses of the intermediate gauge bosons without breaking the local gauge symmetry of the original lagrangian. After two sets of fields transformations and symmetry breaking, one set of gauge fields obtain masses and another set of gauge fields keep massless. If we introduce only one set of gauge fields as we do in Yang-Mills theory, we could not keep the mass term of gauge fields local gauge invariant. We must clearly see that, in constructing electroweak model, it is extremely important to keep local gauge symmetry of the original lagrangian, for the local gauge symmetry of the original lagrangian will make the propagators of the massive gauge bosons have the correct forms and give a Ward-Takahashi identity which will play a key role in the renormalization of the theory. In a word, if we want to introduce the masses of intermediate gauge bosons without using Higgs mechanism, the introduction of these massless gauge bosons can not be avoided, otherwise, the theory is non-renormalizable. In other words, in order to make the theory renormalizable, we must keep the local gauge symmetry of the original lagrangian. In order to introduce the masses of intermediate gauge bosons without violating the local gauge symmetry of the original lagrangian, we must either use Higgs mechanism or introduce two sets of gauge fields in theory. In this paper, we avoid using Higgs mechanism, so we introduce two sets of gauge fields.

The problem of the renormalization of the theory is mentioned several times above, now we will give a more detailed discussion on it. Though a complete strict proof on the renormalizability of the theory , which is very complicated and needs a relatively long time to accomplish, is not obtained yet, we will give some preliminary considerations on this problem. As we have mention before, the original lagrangian of the model has strict local gage symmetry. When we quantize the theory in

path integral formulation, we should take gauge conditions first. If we take proper gauge conditions, we could make the propagators of massive gauge bosons have the following form [11 ]:

$$\frac{i}{k^2 - m^2} \left[ -g_{\mu\nu} + \left(1 - \frac{1}{\xi}\right) \frac{k_\mu k_\nu}{k^2 - m^2/\xi} \right]. \quad (6.1)$$

In this case, it is easy to see that, according to the law of power counting, the general gauge field theory is a kind of renormalizable theory. So is the new electroweak theory. Besides, the local gauge symmetry of the original lagrangian will give a Ward-Takahashi identity which will eventually make the theory renormalizable. According to our knowledge on the renormalization of the standard model, we believe that the new electroweak theory is renormalizable.

Although, in the new electroweak model, there exist massless gauge bosons which have not been found by experiment up to now, there exists no contradictions between high energy experiments and the new electroweak model, because if the parameter  $\alpha$  is small enough, the cross section caused by the interchange of massless gauge bosons will be extremely small. As an example, let's simple discuss  $e^-$  - neutrino scattering. The cross section of  $e^-$  - neutrino scattering cause by the interchange of massless gauge bosons is similar to that of Bhabha scattering whose cross section is proportional to the fourth power of the coupling constant. According to eq.(3.12), the coupling constant of leptons and massless gauge bosons  $Z_2$  is:

$$\sqrt{g^2 + g'^2} \sin\alpha. \quad (6.2)$$

So the cross section  $\sigma_1$  of  $e^-$  - neutrino scattering cause by the interchange of massless gauge bosons is proportional to

$$(g^2 + g'^2)^2 \sin^4\alpha. \quad (6.3)$$

The cross section  $\sigma_2$  of  $e^-$  - neutrino scattering cause by the interchange of massive gauge bosons is proportional to

$$\frac{g^4}{m_W^4} \cos^4\alpha. \quad (6.4)$$

If

$$\alpha \sim 10^{-3}, \quad (6.5)$$

then

$$\sigma_1 \ll \sigma_2. \quad (6.6)$$

That means that the contribution of massless gauge bosons to cross section is much smaller than that of massive gauge bosons. Because massless gauge bosons interact

with electrons, they have contributions to the Bhabha scattering. If  $\alpha$  is in the order of  $10^{-3}$ , then the cross section of  $e^+e^-$  scattering caused by massless gauge bosons is about  $10^{10}$  times smaller than the cross section of  $e^+e^-$  scattering caused by photon. Therefore, if parameter  $\alpha$  is small enough, the introduction of massless gauge bosons in the new electroweak model will cause no inconsistency between theory and experiment.

Up to now, experimental physicists do not find massless intermediate gauge bosons in the high energy experiments. In the new electroweak model, there are three kinds of new particles which do not exist in the standard model. They are  $Z_2$  and  $W_2^\pm$  particles.  $Z_2$  is an electric neutral massless vector particle whose properties are quite similar to those of  $\gamma$  photon. Especially, the interaction properties of  $Z_2$  particle are also quite similar to those of  $\gamma$  photon. The differences between  $Z_2$  particle and  $\gamma$  photon are: 1) the coupling constants between those particles and matter fields are different; and 2)  $Z_2$  particle directly interacts with neutrinos but  $\gamma$  photon does not directly interact with neutrinos. So, we could imagine that it will be very difficult to differentiate  $Z_2$  particle from  $\gamma$  photon and to prove the existence of  $Z_2$  particle directly. In other words, if  $Z_2$  particle exists in nature, there must be electric neutral massless vector particles, i.e.  $Z_2$  particles, mixed in  $\gamma$  photons. The fact that  $Z_2$  particle mixed in  $\gamma$  photon might give us a false impression that  $\gamma$  photon interacts with neutrinos directly.  $W_2^\pm$  particles are electric charged massless vector particles. Of course, it is easy to differentiate  $W_2^\pm$  particles from  $\gamma$  photon. But, because the mass of electron is also very small, it is difficult to distinguish between  $W_2^\pm$  particles and electron in the mass spectrum in the high energy experiment. Maybe we could say that the spins of  $W_2^\pm$  particles and electron are different, we could differentiate them by the information of spin. But if  $W_2^\pm$  particles exist in nature and are produced in the experiment, we may regard them as electron or positron suppose that a corresponding neutrino, which is not detected by the experiment, is produced simultaneously in the experiment, for the total spin of a system which consists of two spin  $\frac{1}{2}$  particles could be 1. So, in the high energy experiment, it will be difficult to differentiate  $W_2^\pm$  particles from electron or positron. On the other hand, if we find electric charged massless vector particles exist in nature, we don't know what it is, because there are no such particles in the standard model. We may think that they are special kind of photons, such as charged photons, or they are electrons or positrons suppose that there are corresponding neutrinos produced in the experiment and the errors of the measurement of masses exist. Besides, the cross section of the production of these massless intermediate gauge bosons is relatively very small, few massless intermediate gauge bosons are produced in the high energy experiment. It is a meaningful work to directly prove the existence of these massless intermediate gauge bosons in the experiment, for if we have proved the existence of these massless intermediate gauge bosons in nature, it would mean

that Higgs particle maybe doesn't exist in nature and it would tell us that which electroweak model is the correct model in describing electroweak interactions.

Although we do not use Higgs mechanism in the new electroweak model, any one who is familiar with the standard model may have found that the vacuum potential  $v$  is very like Higgs field. Indeed, except for the kinematical energy terms of Higgs particle, those terms concern of vacuum potential in the lagrangian are completely the same as those of Higgs scalar fields. But they have essential differences. The most important difference is that, in the lagrangian, Higgs fields have kinematical energy terms but vacuum potential do not have kinematical energy terms. So there should exist a kind of particle corresponding to the Higgs field but there exist no particle corresponding to the vacuum potential. This difference may give us a wrong impression that vacuum potential is a very heavy Higgs particle field. For, in the standard model, if we suppose that the mass of scalar fields is infinity, then the dynamical degree of freedom of Higgs field can never be excited. So we could let:

$$\partial_\mu\Phi \simeq 0. \tag{6.7}$$

This opinion is not correct, because, in the standard model, the coefficient of the mass term of the scalar field  $\Phi$  in the original lagrangian is negative, we could not think that the mass of the scalar field is infinity and could not let all  $\partial_\mu\Phi$  vanish. Therefore, vacuum potential can not be regarded as a very heavy Higgs field. Besides, in the standard model, if we let  $\partial_\mu\Phi$  vanish, then the local gauge symmetry is broken and the theory will be non-renormalizable. Similarly, if we add kinematical energy terms of vacuum potential to the lagrangian of the new electroweak model, then the lagrangian will lose local gauge symmetry and the theory will be non-renormalizable too. Therefore, though vacuum potential and Higgs particle have similar characteristics, they have essential differences.

What is vacuum? In quantum field theory, vacuum is regarded as the ground state which has the lowest energy of the system. In a point of view, vacuum is regarded as a spin-0 scalar field whose 4-momentum is always zero in any condition. It is a special kind of media. In the new electroweak theory, vacuum is regarded as a scalar field which has no dynamical degree of freedom. Because vacuum potential has no dynamical degree of freedom, it carries no energy-momentum. But it could carry some quantum numbers. It serves as a background in which all matters in universe move and evolve, but vacuum itself can not be excited or move. All fields will interact with vacuum when they exist and evolve in vacuum, which had already been expressed in the lagrangian of the new electroweak model. For a quantum system, not only the properties of vacuum affect the dynamical behavior of the system, but also the symmetry of vacuum determines the symmetry of the system. So, when the symmetry of vacuum breaks, the symmetry of our physical world is broken

simultaneously. In this paper, we use  $v$  to represent the influence of the vacuum, and the symmetry breaking of the system is caused by the symmetry breaking of vacuum potential  $v$ . After symmetry breaking,  $v$  has definite value, which means that, in our universe, the vacuum is uniform and the properties of vacuum is stable. In the standard model, the masses of all fields, include quark fields, lepton fields and gauge fields, are generated from their interactions with Higgs field. Now, we could think that the masses of all fields are generated from their interactions with vacuum. This view of point coincides with the interaction picture of the perturbation theory. For example, in the perturbation theory, the self-energy diagram of electron will change the mass of electron and the self-energy diagram is generated from the interactions between vacuum and electron, for if there were no vacuum, there would be no self-energy diagram. So it is natural to think that the masses of all fields are generated from their interactions with vacuum.

Because there exists electric-neutral massless intermediate gauge boson  $Z_2$  which could transmit a long-range force field, there will exist a new long-range force in the new electroweak model. Because the coupling constant of massless intermediate boson field and matter fields is very small, the corresponding long-range force field will be very weak and its macroscopic effects are hard to be detected. Because neutrinos carry weak charge and macroscopic objects could absorb neutrinos, any macroscopic object will tend to be in a state of weak charge neutral. This will make the macroscopic effects of weak long-range force weaker and make the effects of weak long-range force field harder to be detected. If  $\alpha$  is about  $10^{-3}$ , then the weak long-range force is about one million times weaker than electromagnetic force. Generally speaking, except for neutrinos, an object which carries weak charge will also carries electric charge, and electromagnetic interactions are much stronger than weak long-range interactions, so , we could imagine that it would be extremely difficult to find macroscopic effects of weak long-range force. Because electron and proton carry not only electric charge but also weak charge, there are weak long-range interactions mixed in the traditional electromagnetic interactions and the weak long-range interactions will contribute a extremely small part to the spectrum of atoms. Weak long-range force may have some influences on cosmology, for neutrinos carry weak charge and a huge amount of neutrinos exist in universe.

We know that, using Higgs mechanism, we could construct a lot of standard model. But we could construct only one electroweak model by using vacuum potential. The reason is that there is only one vacuum potential corresponding to a symmetry, but we could introduce many Higgs fields corresponding to a symmetry. So, in the new theory, more parts of the lagrangian of the model are fixed by the symmetry. This characteristic is important in theory.

Although we could construct an electroweak model without using Higgs mechanism, this does not mean that Higgs particle does not exist in nature. In this paper, we only want to point out one important thing that, without Higgs particle, we could also construct a correct electroweak model in theory. Whether Higgs particle exists in nature or not should be determined by experiment. But if we find that massless gauge bosons exist in nature, we will say that Higgs particle maybe does not exist in nature.

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