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Article

Higgs Mechanism, Mass Formulas of Hadrons, Dark Matter and Fractal Model of Particle

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Abstract: Based on the Higgs equation, whose soliton solution is substituted into the Dirac coupled equation with Higgs field, in the approximation of non-relativity we derive the Morse potential, whose energy spectrum is the GMO mass formula and its modified accurately form $M = M_0 + AS + B[I(I+1) - S^2/2]$. The same formula can be obtained from the dynamical breaking symmetry. According to the symmetry of s-c quarks, the heavy flavor hadrons which made of u,d and c quarks may be classified by SU(3) octet and decuplet, and some simple mass formulas are obtained, then we predict m(Ξ_{cc})=3715 or 3673MeV, and m(Ω_{cc}^{+})=3946 or 3908.2MeV, etc. Further, Higgs equation and its supersymmetric Higgsino equation possess the nonzero fundamental states, and relate to quantum distributions, repulsive force and dark matter. Based on the extensive quark-preon-prepreon model, the fractal model of particle is proposed. When it is simplified, two fractal dimensions 1.4311337… and 2.0329171… are obtained. This model correlates to Brownian motion, renormalization, many shell model, complex dimension and various scalings, etc.

Keywords: hadron, mass formula, Higgs mechanism, symmetry breaking, heavy flavor, dark matter, fractal

1. Introduction

For the SU(3) symmetry and its broken, a well known GMO mass formula of hadrons is:

$$M = M_0 - AS + B[I(I+1) - (S^2/4)]. \tag{1}$$

For the SU(8) supermultiplets, a simple mass formula is [1]:

$$M = M_0 + \alpha Y + \beta C + \gamma[(Y^2/4) - I(I+1)] + \delta J(J+1), \tag{2}$$

Moreover, the hadron spectrum of the quenched QCD was calculated [2]. The mass spectrum of supersymmetric generalization of QCD was studied [3]. The algebraic methods of hadron spectrum were reviewed [4]. The baryon mass spectrum in a SU(3) hidden gauge symmetry was calculated [5]. The spectrum of baryons with two heavy quarks and the mass spectrum of three-generation models were analyzed [6,7]. Anderson obtained the heavy quark mass scale, and calculated and predicted some masses of light and heavy quark hadrons [8]. The mass formula for the resonances by the micrononcausal Euclidean wave functions are described [9]. Lichtenberg, et al., obtained the formulas of masses of ground-state hadrons, most of which contain heavy-flavor quarks, by the regularities in hadron interactions [10]. Glozman and Riska described the spectrum of the charm hyperons in a chiral quark model [11]. Forcrand, et al., reported the strange and charmed hadron spectroscopy on a lattice theory [12]. Cui solved the BS equation for the hybrid mesons with heavy quarks under instantaneous approximation, and obtained the spectrum of hybrid mesons [13]. Genovese, et al., discussed the isospin-breaking mass differences among baryons in potential models [14].

We proposed a modified accurately mass formula [15-17]:

$$M = M_0 + AS + B[I(I+1) - S^2/2]. \tag{3}$$

We assume that hadrons are formed from the emergence string. Usual string should possess two moving states: oscillation and rotation, so we propose corresponding potential and the equation of the emergence string, whose energy spectrum is namely the GMO mass formula and its modified accurate mass formula (3). These are some relations between the string and observable experimental data. Further, based on the Y-Q and I-U symmetries between mass and lifetime on the general SU(3) theory, we can derive the lifetime formulas of hyperons and mesons:

$$\tau = A[2U(U+1) - Q/2], \tag{4}$$

and $$\tau = A'[(1/2) + 2U(U+1) - Q/2 - Q^2/3]. \tag{5}$$

They agree better with experiments. It is a new method on lifetime of hadrons described by quantum numbers. They are symmetrical with the corresponding mass formulas, and can be unified for mass and lifetime. These formulas may extend to describe masses and lifetime of heavy flavor hadrons [17].

In this paper, based on the Higgs mechanism or the dynamical breaking symmetry, the mass formulas of hadrons are derived, from which the masses of some heavy flavor hadrons are predicted. Higgs mechanism and dark matter, the fractal model of particle are researched.

2. Higgs Mechanism and Mass Formulas of Hadrons

The Higgs mechanism is the extension of the spontaneous symmetry breaking to create mass of hadrons in a gauge invariant theory [18,19]. This is a very powerful standard method. Barenboim, et al., performed an exhaustive analysis of the most general Higgs sector of the minimal left-right symmetric model, and discussed the *CP* properties of the vacuum state and generalizations to the nonminimal Higgs sector [20]. Abdel-Rehim, et al., compared the Higgs sector of electroweak theory with the scalar sector of low energy QCD [21]. Bazzocchi, et al., studied the exact (one-loop) effective potential and some masses of the littlest Higgs model, and concluded that the littlest Higgs model is a solution of the little hierarchy problem [22]. Bagger, et al., exhibited the super-Higgs effect in heterotic string theory by turning on a background antisymmetric tensor *B* field, which breaks spontaneously space-time supersymmetry [23]. In 2012 ATLAS detector at the LHC found 5 decay modes: γγ, bb, ττ, WW and ZZ of Higgs boson in pp collisions at $\sqrt{s}$ =7TeV for the standard model, and obtained mass of Higgs boson is 125GeV [24-26].

The Lagrangian of Higgs breaking is [27]

$$L=-\frac{1}{4}F_{\mu\nu}F^{\mu\nu}+\frac{1}{2}\mu^2A_\mu A^\mu-\bar{\psi}\gamma^\mu(\partial_\mu+ig\gamma^5A_\mu)\psi-m\bar{\psi}\psi-\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi-\frac{1}{2}e_0^2A_\mu A^\mu\varphi^2+\frac{1}{2}m_0^2\varphi^2-\frac{1}{4}f^2\varphi^4. \tag{6}$$

Assume that the interaction between φ and ψ fields is $m_0^2=2a\bar{\psi}\psi$, such the corresponding equations of motion are

$$\gamma^\mu(\partial_\mu+ig\gamma^5A_\mu)\psi+m\psi-a\varphi^2\psi=0. \tag{7}$$

$$\partial_\mu^2\varphi+(m_0^2-e_0^2A_\mu A^\mu)\varphi-f^2\varphi^3=0. \tag{8}$$

$$\partial_\nu F^{\mu\nu}+gf^{ab}A_{a\nu}F_b^{\mu\nu}=(-\mu^2+e_0^2\varphi^2)A^\mu+ig\bar{\psi}\gamma^\mu\gamma^5\psi. \tag{9}$$

If f has a relation with ψ, Eq.(7) will add a φ^4 term, etc. When $A_\mu=0$, Eq.(6) reverts to the Goldstone Lagrangian [28], Eq.(8) is the known Higgs equation:

$$\partial_\mu^2\varphi=-m_0^2\varphi+f^2\varphi^3. \tag{10}$$

Let an integral constant $C=m_0^4/4f^2$ and $|\varphi|<m_0/f$, its soliton solution is

$$\varphi=\frac{m_0}{f}\frac{F-1}{F+1},F=\exp(\pm\sqrt{2}m_0\frac{r-ut}{\sqrt{1-u^2}}+C'). \tag{11}$$

It is namely a kink of the φ^4 equation.

A first approximate of the solution (11) is $\varphi = -m_0 / f$ for F=0. It corresponds to a square potential. When the solution $F = \exp(+\sqrt{2}m_0 \ldots.)$ is neglected,

$$\varphi \approx (m_0 / f)(-1 + 2F - 2F^2) \approx -(m_0 / f)(1 - F)^2, F<1. \qquad (12)$$

The Dirac coupled equation with Higgs field is

$$\gamma^{\mu} \partial_{\mu} \psi + m\psi - a\varphi\psi = 0. \qquad (13)$$

Here *a* is a coupling constant between Dirac field and Higgs boson field. Eq.(13) is left multiplication by $(\gamma^{\mu} \partial_{\mu} + m + a\varphi)$, so we obtain

$$[\partial_{\mu}^2 - m^2 + 2ma\varphi - a^2\varphi^2]\psi = 0. \qquad (14)$$

Because the hadrons possess the SU(3) and SU(6) symmetries, the internal structure of these particles is of low velocity, then their momentums can be neglected in non-relativity. For the stable state, which corresponds to the stable hadrons, Eq.(14) becomes

$$[\Delta - (m - a\varphi)^2]\psi = 0. \qquad (15)$$

Its corresponding radial equation in the spherical coordinate is

$$\frac{1}{r^2} \frac{d}{dr}(r^2 \frac{dR}{dr}) + [-\frac{K(K+1)}{r^2} - (m - a\varphi)^2]R = 0. \qquad (16)$$

For the approximate solution $\varphi = -m_0 / f$, the mass of this hadron adds only a constant, i.e., $m \to m - a\varphi = m + a(m_0 / f)$.

A powerful potential is the Morse function [29] $U(r) = D[1 - e^{-b(r-r_0)}]^2$. Duru, obtained an integral representation for the Green's function of the one-dimensional Morse potential by solving path integrals, and derived the correct bound-state energy spectrum and the wave functions [30]. Killingbeck, et al., constructed an effective Morse potential, which shown the hypervirial perturbation method [31]. Compean, et al., studied the trigonometric Rosen-Morse potential in the supersymmetric quantum mechanics and its exact solutions, which are used in the construction of the quantum-mechanical superpotential [32].

For non-relativity the total energy *E=E'+m*, Eq.(16) may become an approximate form

$$\frac{1}{r^2} \frac{d}{dr}(r^2 \frac{dR}{dr}) + [-\frac{K(K+1)}{r^2} + 2m(E' + a\varphi)]R = 0. \qquad (17)$$

In this case the potential by the solution (12) is

$$U(r) = -a\varphi \approx a(m_0 / f)(1 - F)^2, \qquad (18)$$

where $F = \exp[-\sqrt{2}m_0(r - ut) + C_0] = \exp[-\sqrt{2}m_0(r - r_0)]$. The potential (18) is just the Morse function [29]. Therefore, its energy level is

$$E_{k,n} = E_{0,0} + An + BK(K+1) - Cn^2 - DK^2(K+1)^2 + EnK(K+1). \tag{19}$$

It is the same with the mass formula

$$M = (m' + E'_{0,0}) - AS + BI(I+1) - CS^2, \tag{20}$$

and whose two order form. But n in Eq.(17) as an oscillation quantum number should be positive, i.e., S corresponds to –n. In this case, various constants are:

$A = 2m_0\sqrt{am_0/mf} - (m_0^2/m), B = \hbar^2c^2/2mr_0^2, C = m_0^2/m$, and $M_0 = m' + E'_{0,0}, E'_{0,0}$ =A/2+C/4.

For the $J^p = 1^+/2$ baryon octet, let m'=804.0275*MeV*, am_0/f =832.33*MeV*, and $mr_0^2 = 506.61 MeV(fm)^2, m_0^2/m$ =17.19*MeV*, i.e., M_0 =910.75*MeV*, A=222.04 *MeV*, B=38.43*MeV* and C=17.19*MeV*, so

$$m(n) = 939.5725, m(\Lambda) = 1115.6, m(\Sigma^0) = 1192.46, m(\Xi^0) = 1314.89 \text{ MeV}. \tag{21}$$

Therefore, Eq.(20) agrees completely with the experimental data of the neutral baryons [33]. If C=B/4, Eq.(20) is just the GMO mass formula (1). If C=B/2, i.e., $m_0 = \hbar c/2r_0$, Eq.(20) is a modified accurately mass formula (3). Let $M_0 = 908$, A=228 and *B*=40*MeV*, then

$$m(N) = 938, m(\Lambda) = 1116, m(\Sigma) = 1196, m(\Xi) = 1314 \text{ MeV}. \tag{22}$$

For the $J^{pc} = 0^{-+}$ meson octet, let *A*=0, i.e., $am_0/f = m_0^2/4m$ =C/4=–25.90*MeV*, in which m<0, *B*=–207.22MeV, so

$$m(\pi^0) = 134.96, m(K^0) = 497.6, m(\eta) = 549.4 \text{ MeV}. \tag{23}$$

The neutral mesons agree completely within the range of error [33], and M=m. This is the biggest difference is B>0 and m>0 for baryons, B<0 and m<0 for mesons. Both are fermions and bosons, respectively, which are composed of three and two quarks.

For the $J^p = 3^+/2$ baryon decuplet I=1+(B+S)/2 always holds, so the formula (1) derives a simple equal-spacing result

$$M = (M_0 + \frac{15}{4}B) - (A - 2B)S = M_0' - aS. \tag{24}$$

Let M_0' =1233.91MeV, *a*=146.18MeV, so

$$m(\Delta) = 1233.91, m(\Sigma) = 1380.09, m(\Xi) = 1526.27, m(\Omega) = 1672.45 \text{ MeV}. \tag{25}$$

The formula (3) just derives a more accurate formula

$$M = (M_0 + \frac{15}{4}B) - (A - 2B)S - \frac{B}{4}S^2 = M_0' - aS + bS^2. \tag{26}$$

Let M_0' =1231.8, *a*=156.8 and b=–3.3MeV, so

$$m(\Delta) = 1231.8, m(\Sigma) = 1385.3, m(\Xi) = 1532.2, m(\Omega) = 1672.5 \text{ MeV}. \tag{27}$$

Comparing these values in Eqs.(24) and (27), for the latter M_0'=1231.8, A=183.2 and B=–13.2MeV are different.

From above results we should obtain a conclusion: A Higgs particle cannot produce bigger different masses of various particles. Higgs particle should be different for different baryons and mesons, etc. For example, Barbieri, et al., considered a heavy Higgs doublet model [34].

3. Dynamical Breaking Symmetry and Mass Formulas

The usual Lagrangian of the gauge field of SU(3) symmetrical strong interaction is [35,36]:

$$L=-\frac{1}{4}F_{\mu\nu}F^{\mu\nu}-\bar{\psi}\gamma^{\mu}(\partial_{\mu}+ig\gamma^{5}A_{\mu})\psi-\bar{\psi}\,m\psi. \tag{28}$$

When the vector field A_μ has mass μ, the phenomenological Lagrangian of dynamical breaking is [36]

$$\begin{aligned}L=&-\frac{1}{4}F_{\mu\nu}F^{\mu\nu}+\frac{1}{2}\mu^2A_\mu A^\mu-\bar{\psi}\gamma^{\mu}(\partial_{\mu}+ig\gamma^{5}A_{\mu})\psi-\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi\\&-m\bar{\psi}\exp(\frac{2g\gamma^5}{\mu}\varphi)+\mu A^\mu\partial_\mu\varphi.\end{aligned} \tag{29}$$

Hence the equations of motion are

$$\gamma^{\mu}(\partial_{\mu}+ig\gamma^{5}A_{\mu})\psi+m\exp(\frac{2g\gamma^5}{\mu}\varphi)\psi=0. \tag{30}$$

$$\partial_\mu^2\varphi=\mu\partial_\mu A^\mu+\frac{2g\gamma^5}{\mu}m\exp(\frac{2g\gamma^5}{\mu}\varphi)\bar{\psi}\psi. \tag{31}$$

$$\partial_\nu F^{\mu\nu}+gf^{ab}A_{a\nu}F_b^{\mu\nu}=-\mu^2A^\mu-\mu\partial^\mu\varphi+ig\bar{\psi}\gamma^\mu\gamma^5\psi. \tag{32}$$

When $A^\mu=0$, Eq.(31) becomes

$$\partial_\mu^2\varphi=\frac{2g\gamma^5}{\mu}m\bar{\psi}\psi\exp(\frac{2g\gamma^5}{\mu}\varphi)=ae^{b\varphi}. \tag{33}$$

Let the integral constant is positive (e.g., 1/2), we derive a particular solution

$$\varphi=\frac{1}{b}\ln\frac{b}{2a}\frac{4D}{(1-D)^2},D=\exp(\pm b\frac{r-ut}{\sqrt{1-u^2}}+C'), \tag{34}$$

which is analogous with the soliton solution. We give up the meaningless *D=exp(+b...),* then $D<1,e^{b\varphi}=2bD/a(1-D)^2$. In the approximation of non-relativity, $\sqrt{1-u^2}\approx 1$, $D=\exp[-b(r-r_0)]$, $D/(1-D)^2\approx D$, so

$$e^{b\varphi}=\frac{2b}{a}D=C\exp[-b(r-r_0)]. \tag{35}$$

Eq.(30) is left multiplication by $[\gamma^{\mu}\partial_{\mu}+m\exp(2g\gamma^{5}\varphi/\mu)-ig\gamma^{\mu}\gamma^{5}A_{\mu}]$, we obtain

$$[\partial_{\mu}^{2}+m^{2}\exp(\frac{4g\gamma^{5}}{\mu}\varphi)+2m\exp(\frac{2g\gamma^{5}}{\mu}\varphi)\gamma^{\mu}\partial_{\mu}]\psi-g^{2}A_{\mu}^{2}\psi+2ig\gamma^{5}A_{\mu}\partial_{\mu}\psi=0\,. \quad (36)$$

Because the hadrons possess the SU(3) and SU(6) symmetries, the internal structure of these particles is of low velocity, then their momentums can be neglected in non-relativity. When $A_{\mu}=0$, the total energy $E=E'+m$, Eq.(36) becomes

$$\frac{d^{3}S}{dr^{2}}+\{-\frac{K(K+1)}{r^{2}}+2mE'+m^{2}[1-\exp(\frac{2g\gamma^{5}}{\mu}\varphi)]^{2}\}S=0. \quad (37)$$

The approximate solution (35) of the scalar field φ equation is replaced into Eq.(37), then the potential is the Morse-type function [29] $U(r)=-m[1-Ce^{-b(r-r_0)}]^{2}/2$, the equation is

$$\frac{d^{2}S}{dr^{2}}+[-\frac{K(K+1)}{r^{2}}+2m(E'-U)]S=0. \quad (38)$$

Its energy level is

$$E'_{k,n}=E'_{0,0}+An+BK(K+1)+Cn^{2}-DK^{2}(K+1)^{2}+EnK(K+1). \quad (39)$$

Here let $\mu=i\mu_0$, so $E_{0,0}=-(g/\mu_0)+(g^{2}/2m\mu_0^{2})$, $A=-(2g/\mu_0)+(2g^{2}/m\mu_0^{2})$, $B=1/(2mr_0^{2})$, $C=2g^{2}/m\mu_0^{2}$, etc. Their results are also the same with Higgs mechanism. Further, this method will be able to be extended to other potentials and cases. In a word, it agrees completely with data that Higgs mechanism is applied to the mass spectrum of hadrons.

The mass relations have

$$2[m(N)+m(\Xi)]=3m(\Lambda)+m(\Sigma), \quad (40)$$

$$4[m(N)+m(\Xi)]=7m(\Lambda)+m(\Sigma), \quad (41)$$

$$8m(K^{0})(3981.6)=m(\pi^{\pm})+7m(\eta)(3981.2). \quad (42)$$

They correspond to Eq.(1) and Eq.(3), respectively.

Based on the known theories [37,38], the mass operator of the first broken SU(3) symmetry is [37]

$$O_M=H_{VSI}+H_{MSI}=M_0+AU_3=M+AY+BI(I+1)+CY^{2}. \quad (43)$$

For the famous mass relation (40), C=–B/4 is obtained. For a new mass relation (41) which agrees better, we may obtain C=–B/2 and Eq.(3). In Ref.[38], the mass of the same multiplet "can be split into irreducible parts according to the Clebsch-Gordan series

$$8\otimes8=1\oplus8'\oplus8''\oplus10\oplus\overline{10}\oplus27. \quad (44)$$

Neutrality means that" 10 and $\overline{10}$ are absent, then

$$m_N=(m_1-2m'_8+m''_8-3m_{27}),m_{\Lambda}=(m_1-m'_8-m''_8+9m_{27}), \quad (45)$$

$$m_{\Sigma} = (m_1 + m'_8 + m''_8 + m_{27}), m_{\Xi} = (m_1 + m'_8 - 2m''_8 - 3m_{27}). \quad (46)$$

"Suppose that the mass splitting is generated in a more fundamental Lagrangian by a quark-mass term of the type $\overline{\psi}(a + b\lambda_8)\psi$ carrying only singlet and octet representations and that this property is (miraculously) preserved by the interactions. This would mean that m_{27} vanishes," leading to Eq.(40). If we let $m_{27} = (m'_8 + m''_8)/44 \neq 0$, Eq.(41) will be derived. Furthermore, the primary cause is that Eqs.(3) and (41) (42) agree better with the data, and baryon and meson can be unified by M=m.

4. Heavy Flavor Hadrons and Their Masses

In the standard model quarks are the three generations (u,d) (c,s) and (t,b), whose properties exhibit a better symmetry. Some hadrons including heavy flavor c, b and t quarks have been found, and they are consistent with the SU(N) multiplets. Based on the symmetry of s and c quarks in the same generation, we can suppose that the hadrons, which made of u, d and c quarks, are also the SU(3) symmetry. It is a subgroup of SU(4) of u, d, s and c quarks. Such the eight $J^p = 1^+/2$ baryons: p=uud, n=udd(I=1/2); $\Lambda_c^+ = udc(I=0); \Sigma_c^{++} = uuc, \Sigma_c^+ = udc, \Sigma_c^0 = ddc(I=1)$; and $\Xi_{cc}^{++} = ucc$, $\Xi_{cc}^+ = dcc(I=1/2)$ form an octet too. Since m(N)=939, $m(\Lambda_c^+) = 2285, m(\Sigma_c) = 2453$ MeV, and

$$\frac{m(\Sigma) - m(\Lambda)}{m(\Sigma)} = 0.0645 \approx \frac{m(\Sigma_c) - m(\Lambda_c)}{m(\Sigma_c)} = 0.0681, \quad (47)$$

and $\Sigma_c \to \Lambda_c^+ \pi$ is similar to $\Sigma^0 \to \Lambda\pi$, so we assume that these masses of the octet obey a corresponding mass formulas

$$M = M_0 + AC + B[I(I+1) - (C^2/4)], \quad (48)$$

or
$$M = M_0 + AC + B[I(I+1) - (C^2/2)]. \quad (49)$$

From the two corresponding mass relations we may predict $m(\Xi_{cc}) = 3715$ or 3673MeV. Similarly, the ten $J^p = 3^+/2$ baryons: $\Delta^{++}, \Delta^+, \Delta^0, \Delta^-(I=3/2); \Sigma_c^{++}, \Sigma_c^+, \Sigma_c^0(I=1); \Xi_{cc}^{++}, \Xi_{cc}^+$ $(I=1/2)$ and $\Omega_{ccc}^{++} = ccc(I=0)$ form a decuplet too. Their masses are possibly an equal-spacing rule, i.e.

$$M = M_0 + aC. \quad (50)$$

The $J^p = 0^-$ octet of heavy flavor mesons are $\pi^{+,-}, \pi^0(I=1); D^+ = c\overline{d}, D^0 = c\overline{u}(I=1/2)$ and their antiparticles; $\eta'_c = a(u\overline{u} + d\overline{d}) + b(c\overline{c})$. If their mass relation is:

$$4\text{m(D)}= m(\pi) + 3m(\eta'_c) \text{ or } 8\text{m(D)}= m(\pi) + 7m(\eta'_c), \quad (51)$$

so $m(\eta'_c)$ =2444 or 2114MeV since m(π)=137, m(D) =1867 MeV. For the $J^p = 1^-$ octet, $m(\rho) = 770, m(D^+) = 2010$ MeV, so $m(\eta'_c)$ =2423 or 2187MeV.

These octets and decuplet are a certain cross section of the diagrams of the SU(4) multiplets, respectively. For the $J^p = 3^+/2$ baryons, probably, the masses of the triplet $\Sigma^+, \Sigma^0, \Sigma^-$ (I=1), the doublet $\Xi_c^+ = usc, \Xi_c^0 = dsc$ (I=1/2) and the singlet $\Omega_{cc}^+ = scc$ (I=0) are approximately an equal-spacing rule, then the masses of $\Omega^-, \Omega_c^0 = ssc, \Omega_{cc}^+$ and Ω_{ccc}^{++} should be equal-spacing too. They all obey the formula (50). Such any one of masses of $3^+/2$ baryons including c quark is known again, for example, for $\Sigma^0{}_c(2517.5 \pm 1.4)$ ($J^p = 3^+/2$) [39], then other five masses of other baryons will be able to be estimated.

baryon	Ω^-	Ξ_c	Δ	Σ_c	Ξ_{cc}	Ω_c	Ω_{cc}^+	Ω_{ccc}^{+++}
$m(\exp)$	1672	2644	1231	2516				
$m(est)$	*input*	2666	*input*	*input*	3800	2809	3946	5084

Of course, these baryons obey probably the more accurate mass formulas

$$M = M_0 + aC + bC^2, M = M_0 + a'I + b'I^2, \tag{52}$$

which correspond to Eqs.(3) and (26).

Based on the mass formula (3) and (48), (49), some masses of the heavy flavor hadrons are calculated [40]. These mass relations are similar with Eqs.(40)(41)(42), for example,

$$\begin{aligned} &8m(D^0,1864.5)(14916) = m(\psi,3097) + 7m(\phi,1685)(14892) \\ &= m(\eta_c,2980) + 7m(\rho',1700)(14880) = 5m(\eta_c)(14900), \end{aligned} \tag{53}$$

and $$8m(D^*,2010)(16080) = m(\psi) + 7m(\phi,1853 \pm 10)(16068 \pm 70). \tag{54}$$

$$4m(D^0,1864.5)(7458) = m(\psi) + 3m(\eta,1440)(7417), \tag{55}$$

and $$4m(D^*,2010)(8040) = m(\psi) + 3m(\pi_2,1665 \pm 20)(8092 \pm 30). \tag{56}$$

Some phenomenological mass relations of the heavy flavor hadrons exist:

$$m(\psi,3097) + 3m(\pi^0)(3502) = 6m(K^\pm,494) + m(\eta,549)(3513) = 7m(K^0,498)(3486),$$

$$5m(D^0,1864.5)(9320) = 3[m(\pi^0,135) + m(\eta_c,2980)](9345),$$

$$2m(D^0,1869)(3738) = m(\rho,770) + m(\eta_c,2980)](3750),$$

$$m(D^*)(2010) = m(D^0,1869) + m(\pi^\pm,140)(2009),$$

$$2m(D^*,2010)(4020) = m(\psi) + m(\eta',958)(4055),$$

$$\begin{aligned} &m(\Upsilon,9460) = 2m(\psi,3097) + 6m(K^0,497.7) + 2m(\pi^\pm,139.7)(9459.6) = 3m(\psi) + \\ &m(\pi^\pm)(9431) = 3m(D^*) + m(\chi_0,3415)(9445) = 4m(D^*) + m(E,1430)(9470), \end{aligned}$$

$$m(\Upsilon) + 6m(\pi^0,135)(10270) = 3m(\psi,3097) + 2m(K^\pm,494)(10279),$$

$$2m(B^0,5279)(10558)=m(\Upsilon,9460)+m(h_1,1170)(10630)$$
$$=m(\Upsilon,10023)+m(\eta,549)(10572),$$

$$2m(F^+,1971)(3942)=m(\eta_c,2980)+m(\eta,958)(3938).$$

Moreover, some mass ratios exist:

$$\frac{m(K^0)}{m(\pi^0)}=\frac{497.67}{134.97}=3.687=\frac{m(D^0)}{m(K^0)}=\frac{1864.5}{497.67}=3.752,$$

$$\frac{m(\eta)}{m(\pi^\pm)}=\frac{548.8}{139.57}=3.932=[\frac{m(D^0)}{m(n)}]^2=[\frac{1864.5}{939.57}]^2=3.938,$$

$$\frac{m(K^\pm)}{m(\pi^0)}=\frac{493.65}{134.97}=3.657=[\frac{m(n)}{m(K^\pm)}]^2=[\frac{939.57}{493.65}]^2=3.623,$$

$$[\frac{m(K^\pm)}{m(\pi^0)}]^2=[\frac{493.65}{134.97}]^2=(3.657)^2=13.37=G_s=(G_{ms})^2.$$

Some similar multiplets and mass formulas exist possibly in baryons and mesons including b or t quarks. For instance, both mass spectra of $\psi=c\bar{c}$ and $\gamma=b\bar{b}$ are similar; as in the neutral kaon system, $D^0-\overline{D^0}$ and $B^0-\overline{B^0}$ mixings should exist.

5. Higgs and Dark Matter

At recent, it is affirmed that most of the cosmic matter is dark. Han, et al., studied the next-to-minimal supersymmetric standard model with gauge mediation of supersymmetry breaking, and found that it is feasible to spontaneously generate values of the Higgs boson mass parameters consistent with radiative electroweak symmetry breaking. Messenger sneutrinos with a mass in the range 6 to 25 TeV can serve as cold dark matter [41]. Self-interacting dark matter has been suggested in order to overcome the difficulties of the cold dark matter model on galactic scales. Bento, et al., proposed a scalar gauge singlet coupled to the Higgs boson, which could lead to an invisibly decaying Higgs boson. It is a candidate for this self-interacting dark matter particle [42]. Ellis, et al., calculated dark matter scattering rates in the minimal supersymmetric extension of the standard model with non-universal Higgs boson masses [43]. Chattopadhyay and Roy studied Higgsino dark matter in a supergravity model with nonuniversal gaugino masses [44]. Birkedal-Hansen, et al., investigated the scalar dark matter candidate in a prototypical theory space little Higgs model. They performed a thermal relic density calculation including couplings to the gauge and Higgs sectors of the model, and found that two regions have a dark matter candidate with a mass *O* (100GeV) and another candidate with a mass greater than *O* (500GeV) [45]. Hubisz, et al., investigated the dark matter candidate in the littlest Higgs model with *T*-parity [46].

Supersymmetry is the only symmetry which can give rise to a light, elementary Higgs boson for electroweak symmetry breaking. In the Standard Model the quark and leptons are fermions, and Higgs fields are bosons. This distinction disappears in supersymmetry. In the Standard Model, the electroweak symmetry is broken by introducing a Higgs sector to the theory, which involves an electroweak scalar doublet. The mass squared parameter for this field, m_h^2, determines the order parameter of the symmetry breaking: if it is negative, the electroweak symmetry breaks, while if it is positive, all the elementary particles are massless. Higgs bosons of the minimal supersymmetric standard model have masses of approximately 98 and 114 GeV [47]. A large part of the minimal supergravity model parameter space on the dark matter relic density corresponds to a higgsino lightest superparticle (LSP) of mass $\simeq 1\ \mathrm{TeV}$. Chattopadhyay, et al., looked for a heavy higgsino LSP in collider and dark matter experiments, and concluded that a TeV higgsino is a viable supersymmetric dark matter candidate [48]. Masip, et al., studied Higgsino dark matter in partly supersymmetric models, in which the higgsinos are the only light supersymmetric particles, and the higgsino should have a mass around 1TeV [49]. Mahbubani, et al., studied the minimal model with a dark matter candidate and gauge coupling unification. This consists of the standard model plus fermions with the quantum numbers of supersymmetry Higgsinos and a singlet. It predicts thermal dark matter with a mass that can range from 100GeV to around 2TeV [50]. In any case the equation of Higgsino as a fermion should still be the Dirac-like equation

$$\gamma^{\mu}\partial_{\mu}\varphi - m_0\varphi \pm b\varphi^3 = 0. \tag{57}$$

It is namely the Heisenberg unification equation for m=0. In Eq.(57) the potential is

$$V(\varphi) = m_0\varphi^2/2 \mp b\varphi^4/4. \tag{58}$$

For V=0, these are three fundamental states

$$\varphi = 0\text{, and } \varphi = \pm\sqrt{\pm 2m_0/b}. \tag{59}$$

They are applied to describe vacuum, while the vacuum energy corresponds to the cosmic constant Λ. The solutions of Eq.(57) are

$$\varphi^2 = \frac{m_0/b}{\exp(-2m_0\eta + c) \pm 1}. \tag{60}$$

Eq.(10) corresponds to a potential

$$V(\varphi) = \frac{1}{4}f^2\varphi^4 - \frac{1}{2}m_0^2\varphi^2 + C. \tag{61}$$

For V=0, if $C = m_0^4/4f^2$, there will be two fundamental states

$$\varphi = \pm(m_0/f). \tag{62}$$

They seem to correspond to m>0 for baryons and m<0 for mesons. If C=0, there will be three fundamental states

$$\varphi = 0 \text{, and } \varphi = \pm(\sqrt{2}m_0 / f). \tag{63}$$

At above cases these states $\varphi = -(m_0 / f)$ and $\varphi = -\sqrt{\pm 2m_0 / b}$ should be repulsive forces. They may be candidates of dark matter.

Higgs equation (10) and Higgsino equation (57) should be one of dark matter with supersymmetry. A square of wave function is the probability density in quantum mechanics, so the solution (60) of (57) represents Fermi-Dirac distribution for +1 and Bose-Einstein distribution for –1, respectively. The latter corresponds to the cosmic background radiation, which is consistent with repulsive force and dark matter. The former will possibly emerge if dark matter possesses supersymmetry.

Based on the above calculations, we may estimate quantitatively a ratio between baryons matter and dark matter. Assume that 1). All matter consists of two types of different particles with strong and weak interactions, respectively, in which weak interacting particles is dark matter. 2). Masses of strong interacting particles are produced from Higgs field and its supersymmetric Higgsino field, while the later cannot be measured at present. 3). In Higgs field $\varphi = \pm(m_0 / f)$ are two different results, in which $\varphi = -(m_0 / f)$ is repulsive force and dark matter. If both in the three cases are equiprobability, $\varphi = m_0 / f$ as the baryon matter is only 1/8 of all matter.

Higgs mechanism possesses miraculous effect: It may produce various masses, break different symmetries and be candidate of dark matter. Perhaps, its positive mass produces one of particles, while its negative mass brings dark matter.

Morpurgo shown that the results of calculations of physical quantities (e.g., the magnetic moments and the masses) in a relativistic field theory, which can be parametrized in a way typical of the non-relativistic quark model (NRQM) [51-53]. In a relativistic field theory the most general expression of the magnetic moments of the baryon octet contains ten different types of terms and therefore ten parameters. For the masses, in the flavor-breaking approximation to first order, he obtained a five-parameter formula containing the GMO relation (40) of the octet and the two equal-spacing relations of the decuplet. He proposed a mass formula:

$$\begin{aligned} M &= (M_0 - \frac{9}{2}C) + (3D + \frac{3}{2}E - B)S + \frac{C}{2}[4J(J+1)] + \\ &(D-E)\sum_i (\sigma_i P_i^{\lambda} \cdot 2J) - \frac{E}{2}S[4J(J+1)]. \end{aligned} \tag{64}$$

Form this we can obtain two relations: $m(\Sigma)-m(\Lambda)=-4(D-E)=-4\delta$ =76.86 MeV, and $m(\Xi)+m(N)-2m(\Lambda)=-2\delta$=23.26MeV, Therefore, the formula (64) cannot agree completely with experimental data.

Based on the negative matter developed necessarily from the Dirac negative energy state [54-57], we proposed that main characteristics of the negative matter is the gravitation each other, but the repulsion with all positive matter. It may be the simplest candidate of dark matter, and can explain some characteristics of the dark matter and dark energy. Phantom on dark energy is namely a type of negative matter. Such the positive and negative matters are two regions of topological separation in general case, and the negative matter is invisible. We researched its predictions and possible tests [56], and proposed that the mechanism of inflation cosmos [58] due to a huge repulsive force between the positive matter and negative matter created at the same time in quantum fluctuations. It is created from nothing. From this the many worlds and multiverse are formed. We derived the field equations of the repulsive force between the positive and negative matter, and discussed quantitatively the deflected angle of light. The repulsion between the positive and negative matter may form the hyperboloid of two sheets separated for different worlds composed of spherical spaces of positive or negative matter, and may also form the hyperboloid of one sheet, which is namely a wormhole. The Higgs mechanism is possibly a product of positive and negative matter [58]. The existence of four matters on positive, opposite, and negative, negative-opposite particles may form the most perfect symmetrical world [56].

6. Fractal Model of Particle

In present particle physics it is usually believed that all hadrons consist of quarks. But, so far any free quark is not observed. The baryons of three quark may be described by the Borromean rings with three loops in topology [59-63], here united they stand, divided they fall.

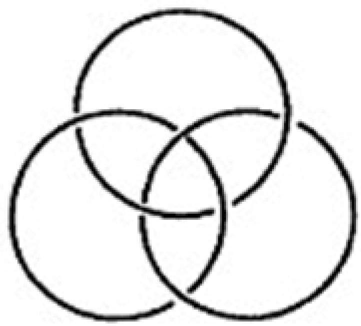

Fig. 1. Borromean rings

Salam, et al., developed the quark model, and assumed that quarks consist of preons (subquarks), and preons consists of prepreons [64], etc. If this embedded structure of particle is extended continuously, and is combined with the fractal geometry which has been applied widely to various aspects of science [65], so the fractal model of particle is obtained [16]. Further, we discuss two simplified geometrical structures.

(I). Assume that a stable baryon consists of three quarks by a stable equilateral triangle in a plane, each quark consists of three preons by the same way, and so on. If this structure is constructed continuously, a self-similar infinite embedded structure is formed, whose area is zero and length is infinite, so this fractal dimension is:

$$D_3 = \frac{\ln 3}{\ln[1+(2\sqrt{3}/3)]} = 1.431133694... \qquad (65)$$

(II). If gluons among quarks are considered, and the momentum of quarks and gluons are fifty-fifty [66], then assume that a baryon consists of three quarks and three gluons by a stable regular octahedron in the three dimensional space, each quark consists of a similar plan, and each gluon consists of six smaller subparticles by a regular octahedron, and so on. Such the final structure is that volume is zero and area is infinite, this fractal dimension is:

$$D_6 = \frac{\ln 6}{\ln(1+\sqrt{2})} = 2.032917136... \qquad (66)$$

It seems just to be unstable when meson consists of two quarks.

According to the mathematical property of the fractal and the above simplified models, we make some brief discussions.

1). The deviation of D_6 is very small with the fractal dimension D=2 of the Brownian motion [67], which shows that the motion inside hadron will tend to Bronian when the survey-length is smaller and smaller at ultrahigh energy. It is the base of the statistical models which may be applied at high energy, and is agreement with the experimental results of the asymptotic freedom in the collisions at high energy.

2). The fractal model must and can be renormalized, which produces the renormalization group. Therefore, this model is a base of the renormalization on the structure of particle. In the renormalization theory, in particular, for the ‘t Hooft dimensional renormalization method, on the hand, the divergent integrals in a four-dimensional space may turn to convergent in a space of smaller dimensionality; on the other hand, in his technique the dimension may be continuous [68]. The former corresponds to that the dimensional number is a smaller fractal, for example, D_6+1. The latter corresponds to the dimension of D_q whose q is continuous and infinite. Here the pure mathematical method is given by the substance.

3). Based on the fractal model, the many shell self-similar embedded structure of particle may be derived naturally, i.e., along with increase in length inside particle, layer upon layer of the structures are similar prepreons, preons (subquarks), quarks and particle. The strange attractor possesses the many shell self-similar structure and the fractal dimension.

4). We have extended the fractal dimension to the complex dimension in both aspects of mathematics and physics [69,16]. When the complex dimension is combined with relativity, it may express a change of the fractal dimension with time or energy, etc [69,16]. The constituents of particle possess different energy in the fractal model, perhaps, the fractal dimension are different, which shows that the correlation strength and the stuffing-power inside particle are different. For instance, $D \approx 2$ corresponds to the statistical models. If the correlations increase, and the Sierpinski sponge is formed, so the fractal dimension D=2.726833…While D=3 corresponds to a hard particle. Different fractal dimensions are namely different phase of particle structure.

5). The many shell self-similar structures possess necessarily invariance under a transformation of some scales. Various scalings possess also invariance under energy scale and corresponding space-time scale, for example, the KNO scaling [70] and the Dao scaling [71], etc. These invariances obtain group, and correspond to the renormalization group.

We researched that the fractal model is applied to some aspects [69,72]. The renormalization group method has been extended to the phase transition theory and the statistical physics from the quantum field theory. Here the fractal applied in statistical physics, etc., is extended to particle physics.

7. Conclusion

Based on the Higgs equation we derive the mass formula of hadron, which may also obtained from the dynamical breaking symmetry. From this some masses of the heavy flavor hadrons are predicted. Further, the relation of Higgs mechanism and dark matter are researched. The fractal model of particle is proposed.

An important tradition of the theoretical physics is that we should derive some calculable values, which may compare with the experiments. Even they include the phenomenological results, since these may probably form a base in order to develop the physical theory. Therefore, we researched quantitatively various mass formulas of particles and the symmetrical lifetime formulas of hyperons and mesons [16,17], and proposed the universal decay formulas of particles and magnetic moment formulas of baryons determined by quantum numbers [73]. While some physical theories are very beautiful, but they have not any quantitative value, so they become pure mathematics.

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