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Two-Flavor Multi-Excitation Model of Quarks

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Abstract

To fully address how quarks get decayed and excited, how particles are formed and generated, and how they interact and transmute, a two-flavor (up & down) multi-excitation (ground & excited) quark model is developed. Based on the author's well-developed innovative four-element theory of nature, the fundamental weak force is surprisingly found to be an interaction between electric and color charges in analogy to the strong force between color charges and the electromagnetic force between electric charges. As a quark is a combination of mass, electric charge, and color charge, the extremely short-range weak force occurs effectively inside quark between its electric and color charges and causes quark's quantized states relaxation (or decay) and excitation via emitting and absorbing quark-antiquark pairs. Leptons are products rather than direct participants of the weak interaction. They are formed from charge annihilations of quarks and antiquarks. A quark has a maximum of eight possible ways to combine with an antiquark and form various particles including mesons, leptons, gluons, Weyl fermions, and photons via different level annihilations. This quark model considers the conventional four heavy flavor quarks: charm, strange, top, and bottom to be the second and third excited states of up and down quarks. Combinations of quarks and antiquarks up to the third excited states can form thousands of different particles, more than currently discovered in nature and from labs. In collisions, leptons would be disintegrated into quarks and antiquarks, which get excited and recombine to form other particles. Collisions of hadrons would excite their quarks and form also various other particles. The higher the energy of collisions is, the more particles are generated.

Keywords

Quark, Excitation, Annihilation, Pair Production, Particle Formation

1. Introduction

According to whether participating in the strong interaction or not, particle physicists have categorized all elementary or subatomic particles observed in nature and discovered in lab experiments into two major categories: hadrons and leptons [1] [2]. Leptons, if neutral, only participate in the weak interaction, and, if electrically charged, also participate in the electromagnetic interaction. Hadrons are composed of quarks and have two broad families: baryons, which are made of an odd number (usually three, qqq) of quarks, and mesons, which are made of an even number (usually two with one being an antiquark, $q\bar{q}$) of quarks [3] [4]. From Large Hadron Collider (LHC) recent experiments, physicists have discovered four-quark mesons, called tetraquarks [5] [6], and five-quark baryons (exotic), called pentaquarks [7] [8].

The conventional quark model suggests that quarks have six flavors, denoted, respectively, by up (u), down (d), charm (c), strange (s), top (t), and bottom (b) [9] [10]. To correspond the six-flavor quarks with the six-flavor leptons, which are named as electron (e^-), muon (μ^-), tau (τ^-) and their corresponding neutrinos (ν_e, ν_μ, ν_τ), scientists usually grouped them into three generations or families (u, d), (c, s), and (t, b) for quarks and (e^-, ν_e), (μ^-, ν_μ), and (τ^-, ν_τ) for leptons [11] [12]. This generation or family correspondences between quarks and leptons may not be factual because all three generations of leptons can be produced from or decay into particles that are only made of the first generation of quarks. For instances, a positively charged pion meson, which is composed of the first-generation quarks (up and antidown), can decay primarily into the second-generation leptons (a positively charged muon and a muon-type neutrino), $\pi^+(u\bar{d}) \to \mu^+ + \nu_\mu$ [13] [14]. A third-generation lepton, negatively charged tau, decays into a negatively charged pion and a neutral pion, which are composed of the first-generation quarks and antiquarks, and a tau-type neutrino, $\tau^- \to \pi^- + \pi^0 + \nu_\tau$ [15] [16]. In addition, around two-thirds of tau leptons decay into hadrons, which are made of quarks, and one-third of them decay into lower generations of leptons such as electrons and muons [17] [18].

Color charge is a fundamental property of quarks and has three varieties: red, green, and blue [19]. Quarks can also be classified into two types: the up-type (u, c, t) with electric charge $2e/3$ and the down-type (d, s, b) with electric charge $-e/3$ [20]. Hadrons participate in the strong interaction via the interaction between their quark's color charges. Antiquarks have color charges to be antired, antigreen, and antiblue, and electric charges to be opposite in signs. All quarks are spin-1/2 fermion particles [21]. Elementary particles are also classified into two types: fermions and bosons, based on their spins to be half-odd-integers or whole integers. In the standard model of particle physics [22] [23], twelve fermions (6 quarks and 6 leptons) are building blocks of matter, four bosons with spin-1 (γ, W, Z, and g) carry the three fundamental (electromagnetic, weak, and strong) interactions, and the Higgs (H) boson with spin-0 is responsible for giving mass to particles [24] [25].

Although the standard model of particle physics has been extremely successful in explaining various observed features of nature, especially in agreement of many predictions with measurements, it still clouds with some critical issues and leaves significant physical phenomena unexplained [26]. For instances, why the universe has more matter than anti-one; how to incorporate with gravitation, described by Einstein's general relativity; how to deal with or account for the dark matter and dark energy, the two major components or mysteries of the universe [27]; why neutrino oscillate [28], how to explain neutron lifetime discrepancy [29], why muons transmutes to electrons (*i.e.*, $\mu 2e$) [30], why neutral leptons and bosons are the same as their antiparticles, why neutrinoless double beta decays occur (*i.e.*, $0\nu\beta\beta$) [31], and so on. It also unclears on how quarks decay and get excited, how particles are formed and generated, and how they interact and transmute. For instances, in the beta decay of a neutron, how the one of two down quarks in the neutron creates a W-boson and then emits or produces leptons are not clear. What the fine structures of Feynman diagrams are for particles' decays, formations, interactions, and transmutations.

This study develops a new model of quarks that have only two flavors or types (up & down) but multiple excitations (ground & excited states), in which the heavy flavor quarks (c, s, t, & b) are treated as the second and third excited up and down quarks. The main difference between light and heavy quarks is their masses or energies. Heavy quarks can decay into light ones. In this paper, we first briefly describe the author's well-developed four-element theory of nature, in which the weak force is an interaction between electric and color charges, and occurs effectively inside a single quark. Then, we explain why quarks have internal structures, how their states are quantized, and how particles are formed from quark-antiquark combinations and/or annihilations. We further demonstrate how quarks decay or transmute, what fine structures of Feynman diagrams are, and how more new particles are formed from combinations and/or annihilations of highly excited up and down quarks and antiquarks in terms of this new quark model. Finally, we show how various leptons and mesons including gamma rays and tetraquarks are formed from electron-positron collisions and discuss how hadron-hadron collisions generate more baryonic and exotic particles. This new quark model may be named as 2-flavor 3-color N-state quark model.

2. Fundamental Elements of Nature

Chemists have found one-hundred and eighteen chemical elements and listed them in the periodic table according to their chemical properties. Physicists have found or predicted fifty-seven elementary particles including gravitons and all antiparticles and listed them in the particle table [32]. Both chemical elements and elementary particles are still not the most fundamental things of nature. Recently, Zhang [33] [34] proposed that nature consists of only four fundamental elements, which are radiation (γ), mass (M), electric charge (Q), and color charges (C). Any known matter or particle is a combination of one or more of the four fundamental elements. For instances as shown in **Table 1**, a photon is radiation only; a neutron has mass only; a Weyl fermion has electric charge only; a gluon has color charge only; a proton is a combination of mass and electric charge, a massless meson is a combination of electric and color charges, and a quark is a combination of mass, electric charge, and color charge (see also recent review of the four-element theory [35]).

The four fundamental elements can be categorized into two types of energies. Mass and radiation are two forms of real energy as Einstein formulated to be proportional to mass and radiation frequency, while electric and color charges are two forms of imaginary energy as proposed and formulated by the author to be proportional to electric and color charges. A pure electric charge such as a Weyl fermion [36], as it is a form of imaginary energy, cannot be directly observed in nature, but its flow or current in semimetals has been recently detected [37]. A pure color charge such as a gluon [38], as it is a form of imaginary energy, cannot be directly observed, but its behavior or existence has been recently detected in quark-gluon plasmas or jet events [39]. In quantum mechanics, a Hamiltonian (e.g. for hydrogen atom) is constructed with kinetic energy and potential energy. Electric charges are imaginary energies, but the electric potential energy between electric charges is real. Hence, Hamiltonian is real, and its eigenvalue is the real-valued energy. In quantum mechanics, an imaginary energy is usually added to explain particles' decay.

Table 1. Four fundamental elements of nature. A particle is a combination of one or more of them.

	Real Energy		Imaginary Energy	
Particles	γ	M	Q	C
Photon	x			
Neutron		x		
Weyl Fermion			x	
Gluon				x
Proton		x	x	
Massless Meson			x	x
quark		x	x	x

The author further showed that among the four fundamental elements there are ten fundamental interactions (**Table 2** and **Figure 1**). Interaction between real energies $\vec{F}_{RR}$ is the gravitational force with three types: $\vec{F}_{\gamma\gamma}$, $\vec{F}_{\gamma M}$, $\vec{F}_{MM}$. The work done by $\vec{F}_{\gamma M}$ on a photon derives the Einsteinian gravitational redshift. Interaction between imaginary energies $\vec{F}_{II}$ is the gauge field force with also three types: $\vec{F}_{QQ}$, $\vec{F}_{QC}$, $\vec{F}_{CC}$, called, respectively, the electromagnetic force between electric charges, the weak force between electric and color charges, and the strong force between color charges. There are additional four imaginary forces between real and imaginary energies $i\vec{F}_{RI}$, which include $i\vec{F}_{\gamma Q}$, $i\vec{F}_{\gamma C}$, $i\vec{F}_{MQ}$, $i\vec{F}_{MC}$. These imaginary forces have no direct observational support but may be

able to address why charges are always associated with or sticked on masses and why gluons are adhesive. All the fundamental interactions are classically unified as a single interaction between complex energies:
$\vec{F}_{EE}=\vec{F}_{RR}+i\vec{F}_{RI}+\vec{F}_{II}=\vec{F}_{\gamma\gamma}+\vec{F}_{\gamma M}+\vec{F}_{MM}+\vec{F}_{QQ}+\vec{F}_{QC}+\vec{F}_{CC}+i\vec{F}_{\gamma Q}+i\vec{F}_{\gamma C}+i\vec{F}_{MQ}+i\vec{F}_{MC}$
(for more details, see also Equation (14) in [33] [35] or **Figure 1**). The strong field between color charges has $SU(3)$ symmetry. The electromagnetic field between electric charges has $U(1)$ symmetry. The weak field between electric and color charges has a symmetry currently unsure and needs further study to find whether it can still be represented as $SU(2)$ or not. In the standard model of particle physics, the weak force occurs between leptons and other particles and has $SU(2)$ symmetry.

Table 2. Fundamental interactions among the four fundamental elements. It is surprisingly found that the weak force is an interaction between electric and color charges. It occurs inside quark rather than among particles with participations of leptons.

Forces	γ	M	iQ	iC
γ	$\vec{F}_{\gamma\gamma}$	$\vec{F}_{\gamma M}$	$i\vec{F}_{\gamma Q}$	$i\vec{F}_{\gamma C}$
M		$\vec{F}_{MM}$	$i\vec{F}_{MQ}$	$i\vec{F}_{MC}$
iQ			$\vec{F}_{QQ}$	$\vec{F}_{QC}$
iC				$\vec{F}_{CC}$

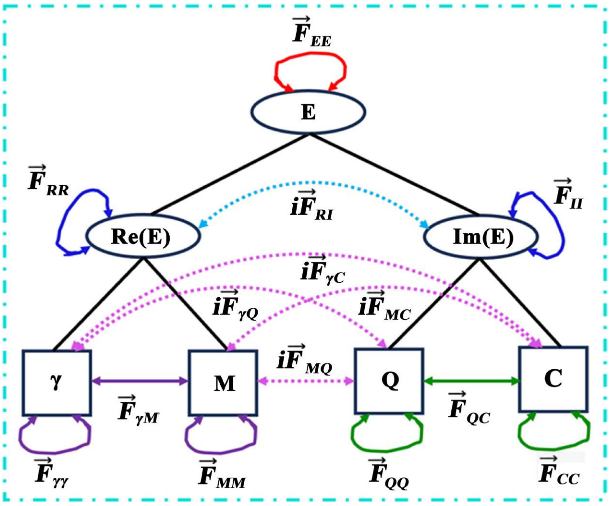

Figure 1. Fundamental interactions among the four fundamental elements of nature [33] [35]. Mass and radiation are real energies, while electric and color charges are imaginary energies. Nature is a system of complex energy, and all fundamental interactions of nature are classically unified into a single interaction between complex energies. There are six real (three gravitational field and three gauge field) and four imaginary interactions among the four fundamental elements.

Electric charges have two types: positive and negative and thus three types of electromagnetic interactions: repel one anther between positive and positive electric charges, repel one another between negative and negative electric charges, and attract one another between positive and negative electric charges. Color charges have three colors: red, green, and blue and thus six types of strong interactions: red-red, red-green, red-blue, green-green, green-blue, and blue-blue interactions. The weak interaction between electric and color charges has also six types: positive-red, positive-green, positive-blue, negative-red, negative-green, and negative-blue interactions. As the weak force is an interaction between different (electric and color) charges and occurs inside a quark, the parity symmetry does not need to conserve in beta decays or emissions of leptons, and the weak charge does not need to exist. Weak force is a quark internal force and strong force is a quark external force. The color charge of a quark may have the weak interaction with the electric charge of another quark or a charged lepton if they are close enough with a distance less than about 10^{-18} m.

3. Quark Structure and State Quantization

As shown above, a quark is a combination of mass, electric charge, and color charge, so that the extremely short-range weak force, as the interaction between electric and color charges, can occur effectively inside a single quark. **Figure 2(a)** (top left panel) gives a schematic diagram for the structure of a quark with three fundamental elements and interactions between the three fundamental elements inside the quark. These interactions, especially the real force (*i.e.*, the weak interaction) $\vec{F}_{QC}$, are believed to play the key role in decays of quarks [33]. The two imaginary forces $i\vec{F}_{MC}$ and $i\vec{F}_{MQ}$ may lead to forming two quarkons by sticking or adhering the color charge on one part of the mass (named as coloron) and sticking or adhering the electric charge on the other part of the mass (named as elecon).

This models the internal structure of a quark as a quantum two-body (*i.e.*, two-quarkon) system, in which the coloron and elecon may oscillate and/or rotate one another with energies and states being quantized to have the ground and excited states, denoted by ($u_0, u_1, u_2, u_3, \cdots$) for an up quark and by ($d_0, d_1, d_2, d_3, \cdots$) for a down quark. The existence of quark's excited states, though not yet directly discovered, has been investigated over three decades [40] [41]. That the meson $\rho^+\left(u\bar{d}\right)$ is also a mixture of one up quark and one down antiquark but has more mass or energy than $\pi^+\left(u\bar{d}\right)$. Many similar examples strongly support that quarks and antiquarks have excited states. It should be noted that the energy and state of a quark or antiquark may be also degenerated by its spin, angular momentum, and color.

Quantum mechanics has shown that the states of such two-body system, like a hydrogen atom or a harmonic oscillator, are quantized with different energies [42]. The weak interaction between electric and color charges inside a quark and the strong interaction between color charges inside and outside the quark vary the states and energies of the quark from one to another. An atom changes its state from one to another by emitting or absorbing a photon, while a quark changes its state from one to another, here we suggest, by emitting or absorbing a quark-antiquark pair (here named as a quark dipole). A single quark is confined [43], while a quark-antiquark pair or dipole is not. **Figure 2(b)** (top right panel) shows the lowest four quantum states of a quark (either up or down quark). The subscript number 0 refers to the ground state (u_0, d_0), the subscript numbers 1, 2, and 3 refer to the first, second, and third excited states (u_1, d_1), (u_2, d_2), and (u_3, d_3).

Using Dirac's notion, we can represent quantum states of quark and antiquark by ket $|q\rangle$ and bra $\langle q|$, respectively. Then, a quark-antiquark pair or combination ($q\bar{q}$) without occurring any annihilation can be denoted as $|q\rangle\langle q|$. The general state of a quark is a linear combination of all quantum states $|q\rangle = \sum_{k=1}^{\infty} c_k |q_k\rangle$, where $|c_k|^2$ is the probability of finding the quark at the quantum state $|q_k\rangle$. Considering that a quark has three different colors, we have $|q\rangle = \sum_{a=r}^{b,g} \sum_{k=1}^{\infty} c_k^a |q_k^a\rangle$. Its conjugate gives the general state of the corresponding antiquark. **Figure 2(c)** (bottom panel) shows that an excited quark lowers its state by emitting a quark-antiquark pair and raises its state by absorbing a quark-antiquark pair.

The early developed preon theory considered quarks and leptons are composites of more basic entities called preons or quips to explain why existence of multiple generations of particles with similar properties [44]-[48]. In the two-flavor multi-excitation model of quarks, a quark is a composite of mass, electric charge, and color charge, which may form two quarkons (*i.e.*, coloron and elecon, in analogy to the preons) via the two adhesive imaginary forces between mass and color charge and between mass and electric charge). The real force between electric and color charges plays the role to excite quarks and cause quarks to decay. Quarks do not have multiple generations but have multiple excitation states. The second and third excited states of up and down quarks are corresponding to the second and third generations of quarks. Hadrons formed from combinations of quarks and antiquarks with states up to the third excited states (192 mesons and 336 baryons) can cover the current experimental spectrum of particles. Quarks are as SU(3) color. Leptons and bosons are formed by charge annihilations of quarks and antiquarks. If quakons or preons are spin-1/4 sub-quark particles, the charge annihilation of quark and antiquark (*i.e.*, the charge annihilation of four spin-1/4 quarkons or preons) can form a lepton with ½-spin such as electron or a boson with spin-0 such as Higgs or spin-1 such as gamma ray.

4. Quark-Antiquark Combination and Particle Formation

There are eight possible ways in maximum for a quark to combine with an antiquark to form various types of particles (**Figure 3**): 1) a meson is formed if no annihilation occurs; 2) a charged lepton occurs if only color charges are annihilated (if spin is integer, the formed one is a charged boson); 3) a neutrino occurs if both electric and color charges are annihilated (if spin is integer, the formed one is a neutral boson); 4) a massive gluon occurs if electric charges are annihilated; 5) a (massless) gluon occurs if masses and electric charges are annihilated;

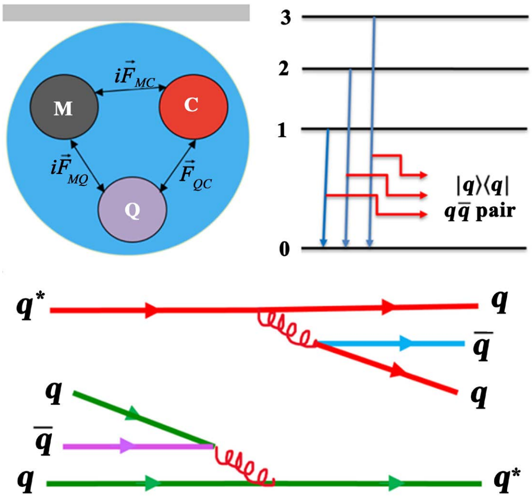

Figure 2. The top left panel shows a schematic diagram for the structure of a quark inside, in which there are mass M, electric charge Q, and color charge C. Among them, there are one real interaction (called the weak force) between Q and C and two imaginary forces between M and Q and between M and C. The top right panel shows that a quark, when it changes its state from one to another, emits or absorbs a quark-antiquark pair, which analogizes to that an atom, when it changes its state from one to another, emits or absorbs a photon. The bottom panel shows that an excited quark q^* relaxes or decays into non-exited quark q by emitting a quark-antiquark pair, while a quark gets excited when it absorbs a quark-antiquark pair.

6) a massless meson occurs if only masses are annihilated; 7) a photon occurs if all masses, electric charges, and color charges are annihilated; and 8) a massless charged lepton or Weyl fermion occurs when masses and color charges are annihilated. These eight quark-antiquark combinations can be denoted as $\langle q|q\rangle_i$ with $i = 1, 2, 3, 4, 5, 6, 7, 8$, corresponding to the eight types of combinations or particles, respectively. A general particle that is formed by combining a quark and an antiquark can be represented as the superposition of the eight possible combinations, $P = \sum_{i=1}^{8} a_i \langle q|q\rangle_i$. In the standard model of particle physics, leptons and bosons are elementary particles, while here we suggest that they are formed or produced from quark-antiquark electric and/or color charge annihilations. In the standard model of particle physics, an eightfold way or diagram is sketched to classify hadrons formed from quark combination with the group $SU(3)$ of flavors. In **Figure 3**, the eight types of quark-antiquark combinations or annihilations among the three fundamental elements (*i.e.*, mass, electric charge, and color charge) may similarly map to a $SU(3)$ group symmetry.

Massive and massless gluons may be considered as candidates of dark matter and dark energy. They have color charges and thus are not directly measurable, but can affect the universe via the strong, weak, and gravitational interactions. Quarks and gluons, if many, form a quark-gluon plasma (QGP), which is usually hot and occurred in the early universe or may be created in labs by hadron-hadron collisions. In addition, neutrinos are usually also considered as a candidate of dark matter. The author recently shows that in the dynamic spacetime neutrinos slow down and rotate around galaxies and affect galactic rotational speed profiles [49].

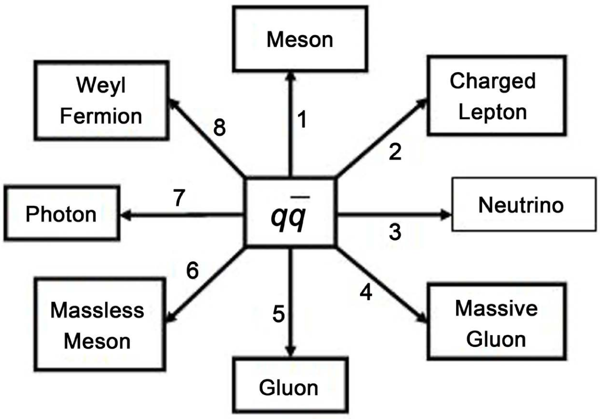

Figure 3. A schematic diagram that shows formations of all eight types of particles from quark-antiquark combinations and annihilations, in which particles with numbers 5, 6, 7, & 8 are massless, particles with numbers 2, 3, 7, & 8 are colorless. Particles with numbers 1, 4, 5, 6, & 7 are bosons; particles with numbers 2, 3, & 8 are fermions, and particles with numbers 2 & 3 can also be bosons when the formed particles have integer spins.

The general particle formed from a quark-antiquark pair is a superposition of these eight-way combinations and annihilations $\sum_{i=1}^{8} b_i \langle q|q\rangle_i$ with $|q\rangle$ and its conjugate $\langle q|$ to be linear combinations of all quantum states with three different colors as given in the first paragraph of this section. Here $|b_i|^2$ is the probability of combining a quark with an antiquark in the i^{th}-way of combinations or forming the i^{th}-type of particles. For a specific pair of quark and antiquark, the number of combinations may be less than 8. For instance, the ground up quark and the first excited antidown quark pair $(u_0\bar{d}_1)$ can only form meson (the electron-mode pion) and charged lepton (tau) but cannot directly annihilate to form neutrino, photon, and others because the up and antidown quark have different masses and electric charges.

As an example, **Table 3** or **Figure 4** shows formations of the first four generation leptons by charge annihilations between up and down quarks and antiquarks in the ground states up to the first excited states [50] [51]. The first-generation leptons are formed by charge annihilations between the ground state up and down quarks and antiquarks $\langle u_0|u_0\rangle_3 \to \nu_e$ or $\bar{\nu}_e$, $\langle d_0|u_0\rangle_2 \to e^+$, and $\langle u_0|d_0\rangle_2 \to e^-$. The second-generation leptons are formed by charge annihilations between the ground state down and excited up quarks and antiquarks $\langle d_0|d_0\rangle_3 \to \nu_\mu$ or $\bar{\nu}_\mu$, $\langle d_0|u_1\rangle_2 \to \mu^+$, and $\langle u_1|d_0\rangle_2 \to \mu^-$. The third-generation leptons are formed by charge annihilations between the ground state up and excited down quarks and antiquarks $\langle u_1|u_1\rangle_3 \to \nu_\tau$ or $\bar{\nu}_\tau$, $\langle d_1|u_0\rangle_2 \to \tau^+$, and $\langle u_0|d_1\rangle_2 \to \tau^-$. The fourth-generation leptons are formed by charge annihilations between excited up and down quarks and antiquarks $\langle d_1|d_1\rangle_3 \to \nu_\lambda$ or $\bar{\nu}_\lambda$, $\langle d_1|u_1\rangle_2 \to \lambda^+$, and $\langle u_1|d_1\rangle_2 \to \lambda^-$. Here, it is seen that a neutrino and its antineutrino are the same particle. They are Majorana particles. Both are created by the color and electric charge annihilations of a quark and its corresponding antiquark. This explains why the big bang universe has more matter than antimatter. The two-flavor multi-excitation model of quarks does not require lepton number to be conserved as it allows neutrinoless double beta decays to occur. As a neutrino is identical to its antineutrino, lepton number of neutrino is undefined. Based on experimental searches and theoretical considerations, the lower limit for the mass of the fourth generation charged lepton is about 100 GeV. It may be too heavy to be produced in current particle accelerators.

Table 3. Leptons that are formed from color and/or electric charge annihilations between the ground and first excited up and down quarks and antiquarks.

	u_0	d_0	u_1	d_1
$\bar{u}_0$	$\nu_e, \bar{\nu}_e$	e^-	?	τ^-
$\bar{d}_0$	e^+	$\nu_\mu, \bar{\nu}_\mu$	μ^+	?
$\bar{u}_1$	?	μ^-	$\nu_\tau, \bar{\nu}_\tau$	λ^-
$\bar{d}_1$	τ^+	?	λ^+	$\nu_\lambda, \bar{\nu}_\lambda$

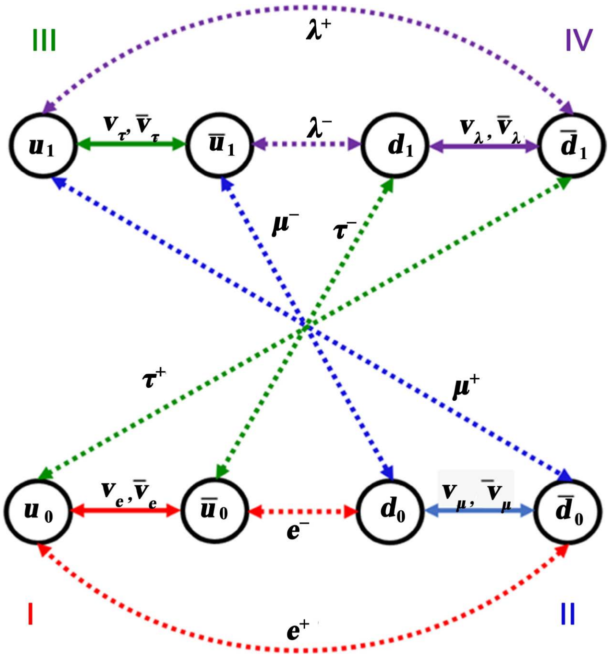

Figure 4. Formations of four-generation leptons from charge annihilations between the ground and first excited up and down quarks and antiquarks.

There are another four quark-antiquark combinations that are question-marked in Table 3: $(u_0, \bar{u}_1)$, $(u_1, \bar{u}_0)$, $(d_1, \bar{d}_0)$, and $(d_0, \bar{d}_1)$, each of these may form or create a pair of gamma rays, a pair of electron, muon, or tau-type neutrino and antineutrino, or a pair of electron, muon, or tau-type charged leptons by the color and/or electric charge annihilations after the excited up or down quarks or antiquarks have decayed. These four quark-antiquark combinations behave like a neutral π-meson π^0 to decay and form particles, mostly two gamma rays. A quark emits a quark-antiquark pair when it lowers its state and absorbs a quark-antiquark pair when it raises its state. For instance, the first excited up quark $|u_1\rangle$ changes its state to the ground state $|u_0\rangle$ after it emits a ground state up quark-antiquark pair $|u_0\rangle\langle u_0|$. This decay mode can be represented as $|u_1\rangle \to |u_0\rangle\langle u_0|u_0\rangle$, where the ground up quark and the ground antiup quark annihilate their charges to form an electron-type neutrino or antineutrino or also annihilate their masses to form a photon. In this case, the quark-antiquark combination $(u_1, \bar{u}_0)$ produces a pair of electron-type neutrino and antineutrino or a pair of gamma rays.

Charge annihilations of up and down quarks and antiquarks with states up-to the third states form leptons up-to the eighth generation. In general, the eight generations of leptons can be represented as $\langle u_i|u_i\rangle_3$ and $\langle d_i|d_i\rangle_3$ for the neutral leptons or neutrinos and $\langle u_i|d_j\rangle_2$ for electrically charged leptons with i and $j = 0, 1, 2, 3$. The fourth or higher generations of leptons are much heavier and hence harder to be observed via current particle accelerators. Annihilation changes the way of binding quarks or antiquarks, so that it changes identity of the state, including rest mass.

5. Quark Decays and Fine Structures of Feynman Diagrams

As mentioned above, the decay of a hadron is a process of the decay of a quark inside the hadron resulting from the weak interaction. The two typical examples of hadron decays are the decay of a neutron (*udd*) into a proton (*uud*) by emitting an electron and an electron-type antineutrino ($n \to p + e^- + \bar{\nu}_e$) and the decay of a proton into a neutron by emitting a positron and an electron-type neutrino ($p \to n + e^+ + \nu_e$).

The first one is the decay of one of the two down quarks in neutron into an up quark with emission of a negatively charged W-boson, which further decays into an electron and an electron-type antineutrino, ($d \to u + W^-$, $W^- \to e^- + \bar{\nu}_e$); while the second one is the decay of one of the two up quarks in proton into a down quark with emission of a positively charged W-boson, which further decays into a positron and an electron-type neutrino, ($u \to d + W^+$, $W^+ \to e^+ + \nu_e$). The standard Feynman diagrams for these two typical decay processes are shown by the left and right panels of **Figure 5**, respectively.

Conventionally, these quark decays or transmutations via the weak interaction take place through exchanging $W^{\pm}$-vector bosons and leptons participate in the weak interaction between quarks and leptons [52]. However, it is unclear and mysterious how one quark's flavor is transmuted or changed to another; how a W-boson comes up when a quark decays or changes its flavor; and how leptons are formed or created and participate in the weak interactions during quark decays or transmutations, etc. All the details of processes are mysterious.

Based on the two-flavor multi-excitation quark model, a neutron is composed of one ground state up quark, one ground state down quark, and one first excited

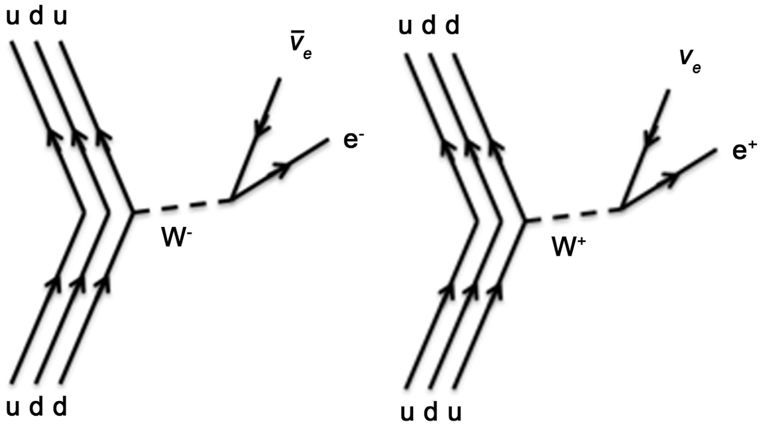

Figure 5. Feynman diagrams for the beta decay of a neutron (left panel) and positron emission of a proton (right panel).

state down quark ($u_0d_0d_1$). When it decays, the excited state down quark in the neutron degenerates into a ground state down quark and, meantime, emits an excited up and antiup quark pair, $d_1 \to d_0 + (u_1\bar{u}_1)$. The excited up quark ($u_1$) of the pair combines with the two quarks (u_0d_0) left by the neutron to form the proton ($u_0d_0u_1$), while the excited antiup quark ($\bar{u}_1$) of the pair further degenerates into a ground state antiup quark and, meantime, emits a ground state up and antiup quark pair, $\bar{u}_1 \to \bar{u}_0 + (u_0\bar{u}_0)$. The ground state antiup quark of the pair annihilates their color charges with the ground state down quark into an electron, $\bar{u}_0 + d_0 \to e^-$ (*i.e.*, $\langle u_0 | d_0 \rangle_2 \to e^-$), while the ground state up quark of the pair annihilates both electric and color charge with the ground state antiup quark into an electron-type antineutrino, $u_0 + \bar{u}_0 \to \bar{\nu}_e$ (*i.e.*, $\langle u_0 | u_0 \rangle_3 \to \bar{\nu}_e$).

Top panel of **Figure 6** shows a schematic diagram for the beta decay of a neutron. The entire process of the beta decay involves two quark-antiquark pair productions or emissions to degenerate excited quarks and two quark-antiquark annihilations to form or create two leptons. One annihilates only the color charge for the formation of electron, while another annihilates both electric and color charges for the formation of electron-type antineutrino. In total, the beta decay of neutron occurs twice weak interactions, twice strong interactions, and once electromagnetic interaction. The spin is not conserved in the quark-antiquark charge annihilation, but, in the entire decay process, it is conserved. The positron emission of a proton has a similar process, also involving two quark-antiquark pair emissions and two quark-antiquark pair annihilations as shown in the bottom panel of **Figure 6**. The positron emission of proton occurs also twice weak interactions, twice strong interactions, and once electromagnetic interaction. It should be noted here that during its decay a quark changes its state rather than changes its flavor or color. In the beta decay, a neutron becomes or transmutes into a proton after one of its down quarks is replaced by an up quark of the emitted quark-antiquark pair. In the positron emission, a proton becomes or transmutes into a neutron after one of its up quarks is replaced by a down quark. The W-bosons are temporarily formed from the combination of the replaced quark with the emitted antiquark.

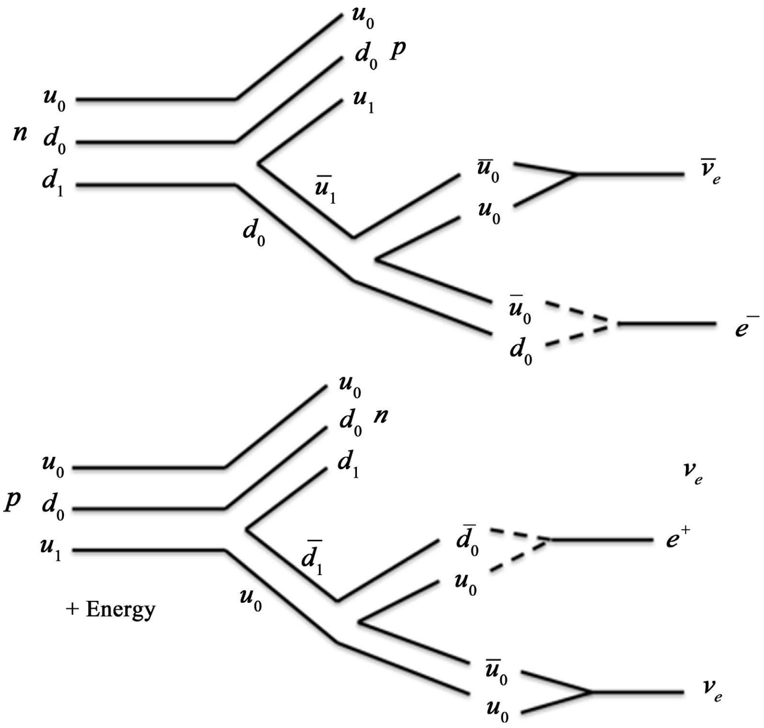

Figure 6. Fine structures of the Feynman diagrams for the beta decay of a neutron (top panel) and positron emission of a proton (bottom panel). Both the beta decay of a neutron and the positron emission of a proton involve two quark-antiquark pair emissions or productions and two quark-antiquark pair charge annihilations.

These give fine structures of the standard Feynman diagrams for beta decays of neutrons and positron emissions of protons. The charged and neutral bosons do not play the role as exchange particles, and the leptons are formed or created from the weak interaction rather than participating in the weak interaction. The weak interaction occurs inside the quark between electric and color charges and causes the quark to decay. The combination of the excited antiup quark with the ground state down quark temporally form the W^- boson. In future study, we will investigate how to calculate the probability of beta decays in terms of the Fermi's golden rule when a quark changes its state from the first excited state to the ground state with quark-antiquark pair productions and develop the Fermi theory of beta decays in the level of quarks with quark-antiquark charge annihilations. These quark-level calculations of beta decays should consider both quark decays to emit quark-antiquark pairs and quark-antiquark charge annihilations to form leptons.

6. Meson and Lepton Formations from Highly Excited Quark-Antiquarks Combinations

The combinations of quarks and antiquarks with quantum states up to their third excited states can form in total 96 types of mesons (32 charged and 64 neutral). As one example, **Table 4** lists charged mesons that are possibly formed by the combination of one up quark and one antidown quark ($u\bar{d}$). Considering the quark and antiquark up to their third excited states, we have $4\times 4=16$ positively charged mesons, denoted in general by M_{ij}^{+} with the subscripts *i* and *j* = 0, 1, 2, 3. In the 16 positively charged mesons, 9 mesons, named as $\pi^{+}, K^{+}, B^{+}, D^{+}, D_s^{+}, B_c^{+}, T^{+}, T_s^{+}$ and T_b^{+} have been observed or investigated in the standard model of particle physics. The other 7 mesons may quicky form leptons via annihilations after their excited quarks decay. The first one, M_{00}^{+}, because it is formed by combining the ground up quark with the ground down antiquark, directly annihilates their color charges into a single positron, $M_{00}^{+}=\left(u_0\bar{d}_0\right)\rightarrow e^{+}$, without a quark decay. The second one, M_{10}^{+}, because it is formed by combining the first excited up quark with the ground down antiquark, directly annihilates their color charges into a single spin-1/2 muon, $M_{10}^{+}=\left(u_1\bar{d}_0\right)\rightarrow \mu^{+}$, without a quark decay. Similarly, we can have 16 negatively charged mesons M_{ij}^{-} to be formed by combinations of one antiup quark and one down quark ($\bar{u}d$).

Table 4. Formations of positively charged mesons from combinations of one up quark with one antidown quark ($u\bar{d}$) up to the third excited states.

$u\bar{d}$	u_0	u_1	u_2	u_3
$\bar{d}_0$	M_{00}^{+}	M_{10}^{+}	M_{20}^{+}	M_{30}^{+}
$\bar{d}_1$	M_{01}^{+}	π^{+}	D^{+}	T^{+}
$\bar{d}_2$	M_{02}^{+}	K^{+}	D_s^{+}	T_s^{+}
$\bar{d}_3$	M_{03}^{+}	B^{+}	B_c^{+}	T_b^{+}

For the neutral mesons, we have in total 64 types, which can be categorized into the up-type 16 neutral mesons, formed by combining one up quark and one antiup quark ($u\bar{u}$), the down-type 16 neutral mesons, formed by combining one down quark and one antidown quark ($d\bar{d}$), the short-type 16 neutral mesons, formed by adding the mix combination $\left(u\bar{d}+\bar{u}d\right)/\sqrt{2}$, and the long-type 16 neutral mesons, formed by subtracting the mix combination $\left(u\bar{d}-\bar{u}d\right)/\sqrt{2}$.

As one example, **Table 5** lists the up-type 16 neutral mesons that are possibly formed by combining one up quark and one antiup quark with states up to their third excited states. They are denoted in general by M_{ij}^{0} with the subscripts *i* and *j* = 0, 1, 2, 3. As antiparticles of neutral mesons are themselves, $M_{ij}^{0}=M_{ji}^{0}$, in the up-type 16 neutral mesons, only 10 of them are independent. In the up-type 10 independent neutral mesons, 3 mesons, named as π^{0}, D^{0}, and J/ψ, have been observed and 3 mesons, named as T^{0}, T_c^{0}, and θ are hypothetical or not observed due to the short lifetime of the top (*i.e.*, the third excited up) quark. The other 4 mesons may quicky form leptons via annihilations after their excited quarks decay. The first one, M_{00}^{0}, because it is formed by combining the ground up quark with the ground antiup quark, directly annihilates into a single gamma ray or an electron-type neutrino, $M_{00}^{0}=\left(u_0\bar{u}_0\right)\to\gamma$ or ν_e, without quark decay. Similarly, we can have 10 independent down-type, 10 independent short-type, and 10 independent long-type neutral mesons. It should be noted here that, distinguishing their color differences, we have in maximum $96\times 3=288$ mesons and, eliminating the short-type and long-type neutral mesons, we have in total 192 mesons. As each type of neutral mesons has six non-independent, we have $\left(96-24\right)\times 3=288-72=216$ mesons.

Table 5. Formations of the up-type 16 (only 10 independent) neutral mesons from the combinations of one up quark with one antiup quark ($u\bar{u}$) up to the third excited states.

$u\bar{u}$	u_0	u_1	u_2	u_3
$\bar{u}_0$	M_{00}^{0}	M_{10}^{0}	M_{20}^{0}	M_{30}^{0}
$\bar{u}_1$	M_{01}^{0}	π^0	D^0	T^0
$\bar{u}_2$	M_{02}^{0}	$\bar{D}^0$	J/ψ	T_c^0
$\bar{u}_3$	M_{03}^{0}	$\bar{T}^0$	$\bar{T}_c^0$	θ

The charge annihilations of quarks and antiquarks with states up to the third excited states can form 96 types of leptons (32 charged and 64 neutral). As one example, **Table 6** lists positively charged leptons that are possibly formed by color charge annihilations of one up quark and one antidown quark ($u\bar{d}$). Considering the up quark and down antiquark with states up to the third excited states, we have $4\times 4=16$ positively charged leptons, denoted in general by L_{ij}^{+} with the subscripts *i* and *j* = 0, 1, 2, 3. In the 16 positively charged leptons, 3 leptons or generations, named as e^+,μ^+, and τ^+, have been observed. The fourth generation λ^+ was predicted by the author in [50] and studied also in [40] [53]. Any of the other 12 leptons or generations may form or decay into a lower generation lepton. Similarly, we can have 16 negatively charged leptons L_{ij}^{-} to be formed by color charge annihilations of one antiup quark and one down quark ($\bar{u}d$) with states up to the third excited states.

Table 6. Positively charged Leptons formed from color charge annihilations of one up quark with one antidown quark ($u\bar{d}$) up to the third excited states.

$u\bar{d}$	u_0	u_1	u_2	u_3
$\bar{d}_0$	e^+	μ^+	L_{20}^{+}	L_{30}^{+}
$\bar{d}_1$	τ^+	λ^+	L_{21}^{+}	L_{31}^{+}
$\bar{d}_2$	L_{02}^{+}	L_{12}^{+}	L_{22}^{+}	L_{32}^{+}
$\bar{d}_3$	L_{03}^{+}	L_{13}^{+}	L_{23}^{+}	L_{33}^{+}

For neutral leptons or neutrinos, we have total 32 types, which can be categorized into the up-type 16 neutral leptons or neutrinos, formed by combining one up quark and one antiup quark ($u\bar{u}$) with charge (both electric and color) annihilations, the down-type 16 neutral leptons or neutrinos, formed by combining one down quark and one antidown quark ($d\bar{d}$) with charge annihilations. There may have the short-type 16 neutral leptons or neutrinos, formed by adding the mix charge annihilation $\left(u\bar{u}+\bar{d}d\right)/\sqrt{2}$, and the long-type 16 neutral leptons or neutrinos, formed by subtracting the mix charge annihilation $\left(u\bar{u}-\bar{d}d\right)/\sqrt{2}$. As one example, **Table 7** lists the up-type 16 neutral leptons or neutrinos that are possibly formed by annihilating both electric and color charges of one up quark and one antiup quark with states up to the third excited states. They are denoted in general by $\nu_e^i,\nu_\tau^i,\nu_c^i,\nu_t^i$, with the subscript i = 0, 1, 2, 3. In the up-type 16 neutral leptons or neutrinos, 2 neutral leptons or neutrinos, named as ν_e,ν_τ , have been observed. The other 14 neutral leptons or neutrinos may be formed if the annihilations occur or may not be formed if the excited quarks decay before annihilations occur. It should be noted that the up-type 16 neutral leptons or neutrinos are not independent because the six of them are antineutrinos of the other six neutrinos such as $\nu_e^1=\bar{\nu}_\tau^0$. The diagonal 4 neutrinos and their antiparticles are the same ones.

Table 7. Up-type neutral leptons or neutrinos formed from both electric and color charge annihilations of one up quark with one antiup quark ($u\bar{u}$) up to the third excited states.

$u\bar{u}$	u_0	u_1	u_2	u_3
$\bar{u}_0$	$\nu_e^0=\nu_e$	ν_τ^0	ν_c^0	ν_t^0
$\bar{u}_1$	$\nu_e^1=\bar{\nu}_\tau^0$	$\nu_\tau^1=\nu_\tau$	ν_c^1	ν_t^1
$\bar{u}_2$	$\nu_e^2=\bar{\nu}_c^0$	$\nu_\tau^2=\bar{\nu}_c^1$	ν_c	ν_t^2
$\bar{u}_3$	$\nu_e^3=\bar{\nu}_t^0$	$\nu_\tau^3=\bar{\nu}_t^1$	$\nu_c^3=\bar{\nu}_t^2$	ν_t

Table 8 lists the down-type 16 neutral leptons or neutrinos that are possibly formed by annihilating both electric and color charges of one down quark and one antidown quark with states up to the third excited states. They are denoted in general by $\nu_\mu^i,\nu_\lambda^i,\nu_s^i,\nu_b^i$, with the subscript i = 0, 1, 2, 3. In the down-type 16 neutral leptons or neutrinos, 1 neutral lepton or neutrino, named as ν_μ , has been observed as the second generation of leptons. 1 neutral lepton or neutrino, named as ν_λ , is one predicted by the author as the fourth generation of leptons [50]. The other 14 neutral leptons or neutrinos may be formed if the annihilations occur or may not be formed if the excited quarks decay before annihilations occur. It should be noted that the down-type 16 neutral leptons or neutrinos are not independent because the six of them are antineutrinos of the other six neutrinos such as $\nu_\mu^1=\bar{\nu}_\lambda^0$. The diagonal 4 neutrinos and their antiparticles are the same ones.

Table 8. Down-type neutral leptons or neutrino formed from both electric and color charge annihilations of one down quark and one antidown quark ($d\bar{d}$) with states up to the third excited states.

$d\bar{d}$	d_0	d_1	d_2	d_3
$\bar{d}_0$	$\nu_\mu^0=\nu_\mu$	ν_λ^0	ν_s^0	ν_b^0

Continued

$\bar{d}_1$	$\nu_\mu^1 = \bar{\nu}_\lambda^0$	$\nu_\lambda^1 = \nu_\lambda$	ν_s^1	ν_b^1
$\bar{d}_2$	$\nu_\mu^2 = \bar{\nu}_c^0$	$\nu_\lambda^2 = \bar{\nu}_s^1$	ν_s	ν_b^2
$\bar{d}_3$	$\nu_\mu^3 = \bar{\nu}_b^0$	$\nu_\lambda^3 = \bar{\nu}_b^1$	$\nu_s^3 = \bar{\nu}_b^2$	ν_b

The formations of particles via other types of annihilations shown in Figure 3 leave for future studies. Considering up & down quarks with three different colors, two different flavors, four different states, and maximum eight different ways of combinations with antiquarks, which also have two different flavors and four different states, we can estimate the maximum number of probably formed particles (or combinations) to be 3 × 2 × 4 × 8 × 2 × 4 = 1536 particles, many of these not yet observed. Number of mesons will be 1536/8 = 192. Including the short-type and long-type of neutral mesons, we have in total 288 mesons. Removing the 72 non-independent neutral mesons, we have 216 mesons. We further notice that some observed mesons may have different types or flavors. For an instance, the π^+ meson may have electron type or mode $\pi_e^+\left(u_1\bar{d}_0\right)$, which decays into e^+ and ν_e and muon type or mode $\pi_\mu^+\left(u_1\bar{d}_1\right)$, which decays into μ^+ and ν_μ or π^0, e^+ and ν_e. Up to the *N*-th excited states, the maximum number of possibly formed particles from the eight types of combinations will be $96N^2$.

In future studies, we will address processes of meson decays and give the corresponding fine structures of Feynman diagrams. A quark and antiquark with the same flavor and state, such as ($u_0\bar{u}_0$), can form a gamma ray when masses, electric and color charges are all annihilated, a neutrino when electric and color charges are annihilated, and a gluon when masses and electric charges are annihilated. A quark and antiquark with the same flavor but different states, such as ($u_0\bar{u}_1$), can form a temporal meson, which decays into two or more particles after the excited quark or antiquark decays with an emission a quark-antiquark pair.

7. Particle Formation from Electron-Positron Collisions

In an energetic electron-positron collision, the electron and positron are first disintegrated into quark-antiquark pairs ($e^- \to \bar{u}_0 d_0$, $e^+ \to u_0\bar{d}_0$). The process of lepton disintegration is an inverse process of quark-antiquark charge annihilations. Then, during the collision, the quarks and antiquarks that are disintegrated from the electron and positron absorb energy and get excited. Third, those excited quark-antiquark pairs annihilate their color charges to form higher generations of electrically charged leptons.

Figure 7 shows a typical example for the second through fourth generations of leptons to be formed from electron-positron collisions. When the antiup quark in the disintegrated electron quark-antiquark pair and the up quark in the disintegrated positron quark-antiquark pair are excited, then the annihilations produce $\mu^\pm$ leptons. When the down quark in the disintegrated electron quark-antiquark pair and the antidown quark in the disintegrated positron quark-antiquark pair are excited, then the annihilations produce $\tau^\pm$ leptons. When both the antiup and down quarks in the disintegrated electron quark-antiquark pair and both the up and antidown quarks in the disintegrated positron quark-antiquark pair are excited, the annihilations produce the $\lambda^{\pm}$ leptons. An electron-positron collision in a different energy level produces a different generation of electrically charged leptons. And so on, in general, to produce a higher generation of leptons, a more energetic electron-positron collision is required.

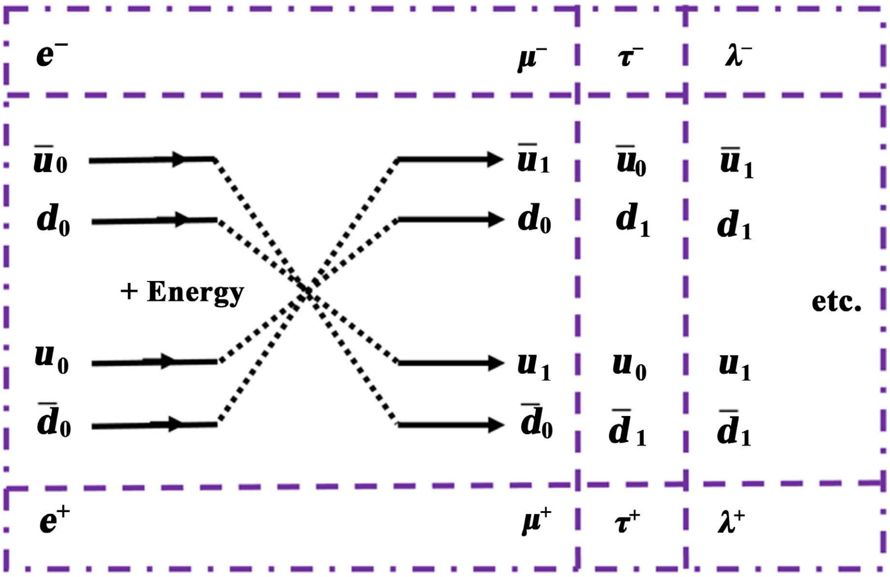

Figure 7. Productions of other three electrically charged leptons from energetic electron-positron collisions. During an electron-positron collision, the electron and positron are first disintegrated into quark-antiquark pairs, which are then excited and further annihilated into other generations of electrically charged leptons. The fifth or higher generations of leptons are probably formed when the electron-positron collision is more energetic.

The disintegrated electron and positron quark-antiquark pairs from electron-positron collisions, when they are excited but not annihilated, can form mesons such as $\pi_e^{\pm}$, $\pi_\mu^{\pm}$, $D^{\pm}$, $B^{\pm}$, and so on (Figure 8). When the up and antiup quarks that are disintegrated from electron and positron are excited to the first excited states, then the combinations (without charge annihilations) produce electron type or mode pion mesons $\pi_e^{\pm}$ or bosons $W^{\pm}$ if color charges are annihilated with spin to be 1. When all the up and down quarks and their antiquarks that are disintegrated from electron and positron are excited to the first excited states, then the combinations without charge annihilations produce muon type or mode pion mesons $\pi_\mu^{\pm}$ (or the regular pion meson $\pi^{\pm}$). When the up and antiup quarks that are disintegrated from electron and positron are excited to the second excited states, while the down and antidown quarks that are disintegrated from electron and positron are excited to the first excited states, then the combinations without charge annihilations produce $D^{\pm}$ mesons. An electron-positron collision in a different energy level produces a different generation of electrically charged mesons. And so on, in general, to produce a higher generation of mesons, a more energetic electron-positron collision is required.

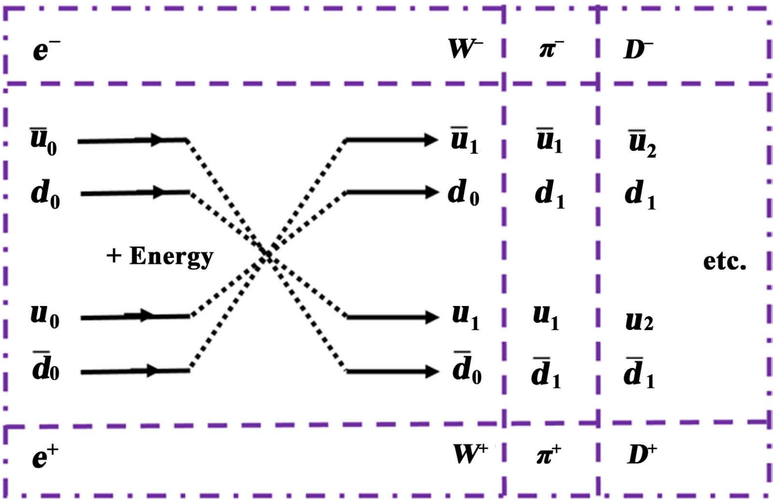

Figure 8. Productions of electrically charged mesons and W-bosons from energetic electron-positron collisions. In an electron-positron collision, the electron and positron are first disintegrated into quark-antiquark pairs, which are then excited and combined into mesons without occurring quark-antiquark annihilations and into bosons with color charge annihilations when spin is 1.

The quark-antiquark pairs $(\bar{u}_0, d_0)$ and $(u_0, \bar{d}_0)$, which are disintegrated from electron and positron, can form a pair of electron-type neutrino and muon-type antineutrinos $(\nu_e, \bar{\nu}_\mu)$ or $(\bar{\nu}_e, \nu_\mu)$, when the quark and antiquark are not excited but regroup according to their flavors into $(\bar{u}_0, u_0)$ and $(d_0, \bar{d}_0)$ and further annihilate both electric and color charges (Figure 9). They can also form or annihilate into a pair of muon-type neutrino and tau-type antineutrino, $(\nu_\mu, \bar{\nu}_\tau)$ or $(\nu_\tau, \bar{\nu}_\mu)$, when the up and antiup quarks are excited, and a pair of tau-type and lambda-type neutrinos, $(\nu_\tau, \bar{\nu}_\lambda)$ or $(\nu_\lambda, \bar{\nu}_\tau)$, when all the up and down quarks and antiquarks are excited. The neutrino and antineutrino in each pair are not the same type.

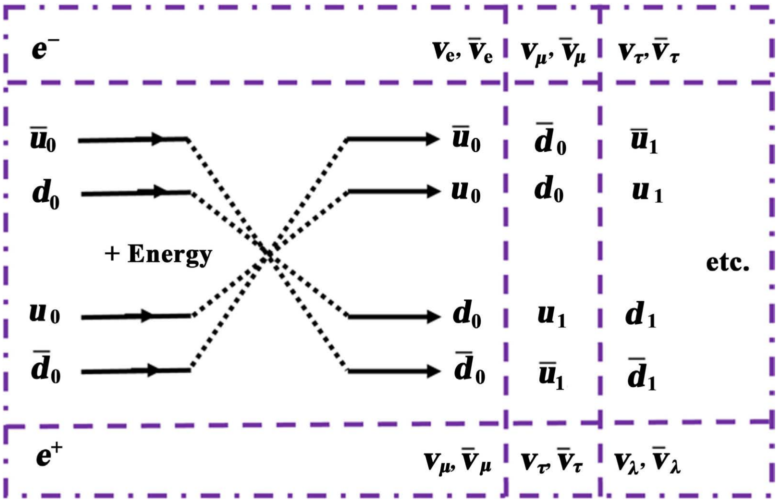

Figure 9. Formation of pairs of various types of neutrinos and antineutrinos from electron-positron collisions with quark disintegrations, state excitations, and charge annihilations.

When the quark-antiquark pairs annihilate not only their electric and color charges but also their masses, various pairs of gamma rays can form from electron-positron collisions or annihilations (**Figure 10**). Surprisingly, the two gamma rays in each pair are not identical. Here, that the electron-positron annihilation produces two different gamma ray photons is one of the most critical new findings from the two-flavor multi-excitation quark model. Accurately measuring the frequencies or energies of the two photons generated from the electron-positron annihilation may be helpful in testing and confirming this new quark model. In general, what kinds of particles are formed or created from electron-positron collisions depends on how the quark and antiquark excite, regroup, combine, and annihilate. The pair of photons are quantum-mechanically entangled. When one is measured to be the electron-type gamma ray, then the other should be measured to be the muon-type gamma ray. But if one is measured to be the muon-type gamma ray, then the other will be measured to be either the electron-type gamma ray or the tau-type gamma ray. Similarly, when one is measured to be tau-type gamma ray, then the other will be measured to be either the muon-type gamma ray or the lambda-type gamma ray.

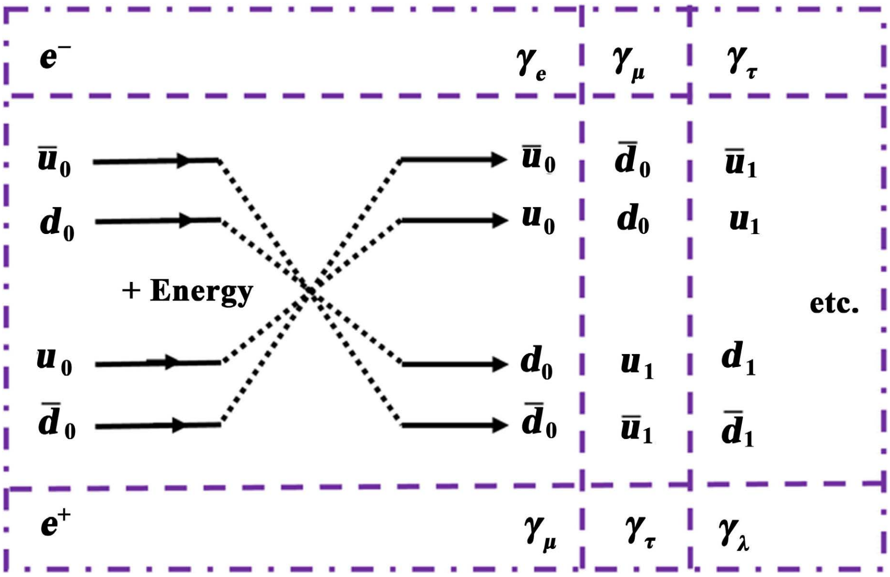

Figure 10. Formation of pairs of various types of gamma rays from electron-positron collisions with quark disintegrations, state excitations, and complete annihilations. Like neutrinos, the gamma rays emitted from annihilations of quark-antiquark pairs that are disintegrated from electron and positron have different types.

It is well known that a high-energy or frequency gamma ray photon, when it interacts with a nucleus, can be materialized into a particle-antiparticle pair such as an electron-positron pair. Here, we suggest that the pair-production process involves three steps (**Figure 11**): 1) the gamma ray photon is disintegrated into a quark-antiquark pair, e.g. $(u_0, \bar{u}_1)$, in which one quark, e.g. $\bar{u}_1$, is excited; 2) the excited antiup quark degenerates to the ground state and meantime emits a down quark-antiquark pair, $\bar{u}_1 \to \bar{u}_0 + \left(d_0\bar{d}_0\right)$; and 3) the two quark-antiquark pairs annihilate their color charges into electron and positron, $\left(\bar{u}_0 d_0\right) \to e^-$ and $\left(u_0\bar{d}_0\right) \to e^+$. It should be pointed out that, when the excited antiup quark degenerates to the ground state and meantime emits an up quark-antiquark pair, $\bar{u}_1 \to \bar{u}_0 + \left(u_0\bar{u}_0\right)$, then the photon is materialized into a pair of neutrino and antineutrino or is split into two photons. Measuring pair production of neutrino and antineutrino or two photons from a single photon can also help to test and confirm this new quark model.

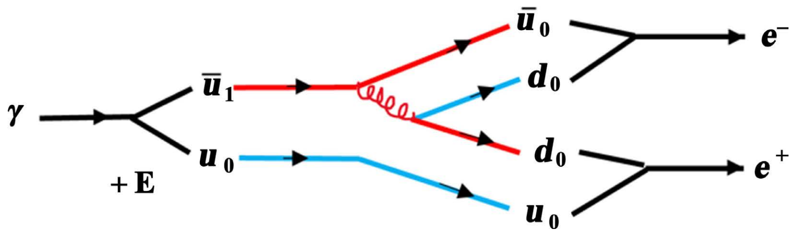

Figure 11. Electron-positron pair-production of a high-energy or frequency gamma ray photon. It involves disintegration of the photon into a quark-antiquark pair, degeneration of the excited antiup quark to its ground state with emission of a ground down quark-antiquark pair, and color charge annihilations of ground up and down quark-antiquark pairs into an electron and a positron.

Like a high-energy or frequency gamma ray photon, a lepton including neutrino, when it interacts with a particle or nucleus, can be disintegrated into a quark-antiquark pair. Decays and oscillations of neutrinos can be understood or explained with neutrino disintegrations, quark excitations, quark-antiquark pair emissions, and annihilations [50].

8. Discussions

We have suggested the Pauli exclusive principle is applicable to quarks in a particle. There are no two quarks having the same flavor and state inside a particle. For three quarks (*qqq*) with two flavors, three colors, and four excitation states to combine or make a baryonic particle, there are in total $C_{2\times3\times4}^3 = C_{24}^3 = 2024$ possible combinations or types of particles to be formed. As baryons are color neutral, the number of baryons that are probably formed are much less than 2024 and can be $8\times7\times6 = 336$ when the Pauli principle is applied. Much more four-quark mesons and five-quark exotic baryons can be formed. In general, quarks can have infinite quantum states. Combinations of quarks with infinite quark states produce infinite types of particles.

Considering radiation energy to be equivalent to mass, we can simplify the four-element theory of nature to a three-element theory of nature. Among them (*i.e.*, mass, electric charge, and color charge), there are four real fundamental interactions: the gravitational interaction between masses, the electromagnetic interaction between electric charges, the strong interaction between color charges, and the weak interaction between electric and color charges. There are two extra imaginary interactions: one between mass and electric charge and another between mass and color charge. Electric charge sticking on mass forms an electrically charged particle. Color charge sticking on mass or radiation forms a massive or massless gluon. Inside a quark, we have named them as elecon and coloron, two types of quarkons. A nucleus is a composite of nucleons with two types: proton and neutron. A nucleon is a composite of quarks with two types: up and down. A quark is a composite of quarkons with two types: elecon and coloron. Here quarkons are analogs of preons.

Spin conservation may not be warranted during electric and/or color charge annihilations of quarks and antiquarks. As shown in Section 4 or **Figure 3**, a spin-1/2 quark and a spin-1/2 antiquark can form a spin-1/2 lepton or a spin-1 boson through charge annihilations. Future study will address the spin of particles, a fundamental property of particles, in more details. If quarkons (*i.e.*, elecon and coloron) have a spin of 1/4, then formation of spin-1/2 lepton from quark-antiquark charge annihilation is understandable from the view of particle spin. In the entire decay process, the spin is conserved.

In future studies, we will also attempt to develop theories of two-flavor multi-excitation quark model. First, we will develop quantum mechanics of quarks. We will model a quark as a two-body (*i.e.*, coloron-elecon) quantum system with a weak interaction perturbation and solve the Schrodinger equation with a weak (or electric-color charge interaction) potential to find quantum states $\psi_{nk}(r)$ and energy E_{nk}, where the subscript $n = 1$ for up quark and $n = 2$ for the down quark and the quantum number $k = 0, 1, 2, 3, \cdots$ for the ground, first, second, and third excited states, and so on. A general stationary state of a quark can be represented as

$$\Psi_n(r,t) = \sum_{k=1}^{\infty} c_{nk}\psi_{nk}(r)\exp\left(-\frac{iE_{nk}}{\hbar}t\right)$$

where $\hbar$ is the reduced Planck constant.

Then, we will develop the quantum chromodynamics for this two-flavor multi-excitation quark model. In the two-flavor ($n = 1, 2$) multi-excitation ($k = 0, 1, 2, 3, \cdots, \infty$) quark model, the quantum chromodynamic Lagrangian may be revised to,

$$\mathcal{L} = \sum_{n=1}^{2}\sum_{k=0}^{\infty}\bar{q}_{nk}\left(i\hbar cD - m_n c^2\right)q_{nk} - \frac{1}{4}G^{\alpha}{}_{\mu\nu}G_{\alpha}{}^{\mu\nu}$$

where c is the speed of light in the vacuum, m_n is the mass of the quark, $D = \gamma^{\mu}\left(\partial_{\mu} - ieA_{\mu}\right)$ with A_{μ} the electromagnetic field four-potential, $G^{\alpha}{}_{\mu\nu}$ is the gluon field strength tensor with the superscript α the color index, and q_{nk} is the Dirac spinor of the quark with subscripts n and k representing the flavor and state of the quark. From this Lagrangian, we will determine the masses of up and down quarks.

The beam and bottle experiments have measured a discrepancy of about nine seconds for the lifetime of neutron decays. One probable cause is that some neutrons decay into unseen or dark particles, which can be considered as a candidate of dark matter, rather than protons. Based on the two-flavor multi-excitation quark model, a neutron, when its excited down quark degenerates to the ground state by emitting a quark-antiquark pair with a different color, does not decay into a proton, an electron, and an antineutrino, instead, forms a gluon with three quarks glued by the gluon or a five-quark exotic baryon or pentaquark. Future study will address this in more details.

9. Conclusions

As consequences, this paper develops a two-flavor multi-excitation quark model based on author's innovative thoughts and creative ideas that nature consists of four fundamental elements: radiation, mass, electric charge, and color charge; the weak force is an interaction between electric and color charges and occurs inside quarks; and quarks have only two flavors but multiple excited states. Decays of a quark result from the internal weak interaction between electric and color charges inside the quark. Excitations of a quark result also from the external strong interaction between color charges with other quarks. Quarks change their states by emitting or absorbing quark-antiquark pairs. There are a maximum of eight possible ways for a quark to combine and/or annihilate with an antiquark to form a particle with corresponding eight types, including mesons, charged leptons, neutrinos, massive gluons, gluons, massless mesons, photons, and Weyl fermions. The two-flavor multi-excitation quark model predicts many more other particles for experimental detections. In electron-positron collisions, various particles are created through lepton disintegrations, quark excitations, and annihilations. In future, we will study in more details how three quark baryons are formed and how various particles are formed during the energetic hadron-hadron collisions. We can also explore how four quark mesons (or tetraquarks) and five quark baryons (or pentaquarks) are formed and decay.

Overall, based on this two-flavor multi-excitation quark model, nature has only two building blocks, which are up and down quarks, and consists of four fundamental elements, which are radiation, mass, electric charge, and color charge, and ten fundamental interactions, which are unified into a single interaction between complex energy. Any particle is a combination of one or more of these four fundamental elements and is formed by various combinations of two or more of the two types of quarks in different states. The weak force occurs inside quark, while the electromagnetic and strong forces occur between quarks. In other words, the weak force is a quark internal force, while the electromagnetic and strong forces are quark external forces. In quantum field theory, as particles are fields, interactions between them do not need carriers. The general particles that can be built by the two building blocks include three diquarks: $(u\bar{u})$, $(u\bar{d})$, & $(d\bar{d})$; four triquarks: (uuu), (uud), (udd), & (ddd); six tetraquarks: $(uu\bar{u}\bar{u})$, $(ud\bar{u}\bar{u})$, $(dd\bar{u}\bar{u})$, $(ud\bar{u}\bar{d})$, $(ud\bar{d}\bar{d})$, & $(dd\bar{d}\bar{d})$; ten pentaquarks: $(uuuu\bar{u})$, $(uuud\bar{u})$,

$\left(uudd\bar{u}\right)$, $\left(uddd\bar{u}\right)$, $\left(dddd\bar{u}\right)$, $\left(dddd\bar{d}\right)$, $\left(uddd\bar{d}\right)$, $\left(uudd\bar{d}\right)$, $\left(uuud\bar{d}\right)$ & $\left(uuuu\bar{d}\right)$; and so on.

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Conflicts of Interest

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

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