

Pion States and Decay Modes in the Two-Flavor Multi-Excitation Quark Framework

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Pion states and decay modes are investigated based on the author's newly developed two-flavor multi-excitation model of quarks, in which quarks have only two flavors, denoted also as up and down, but they possess multiple excitation states. The foundation of this new quark model to be developed is the author's well-developed new four-element theory of nature, which proposes the weak force to be an interaction between electric and color charges in analogy to the electromagnetic force to be an interaction between electric charges and the strong force to be an interaction between color charges. As a quark is a composite of mass, electric charge, and color charge, the weak force between electric and color charges occurs inside quark and is responsible for quark excitations and decays. This new quark model has revealed a new quantum world of quarks that provides a deep understanding of how quarks excite and decay, how particles are formed and generated, and how they interact and transmute. We have investigated how leptons are formed via quark-antiquark pair emissions and annihilations, how baryons such as protons and neutrons decay, how a dark matter candidate, called nonaquark, is formed via a two level color charge binding, and so on, in our previous studies. This study attempts to explore the lightest meson, pions, from this new quantum world of quarks insight into their natures, states, and decay modes and to establish the fine structures of Feynman diagrams for their fine processes of transmutations and decays. Results obtained indicate that pions exist different quark and antiquark compositions and states and hence possess various decay modes as observed.

1 Introduction

In particle physics, pions are subatomic particles, composed of a quark and an antiquark, with three different charge states denoted by π^+ , π^- , and π^0 . They are the lightest type of mesons, classified as bosonic hadrons and participating in the strong interaction. Pions were predicted theoretically in 1935 [1], observationally discovered in cosmic rays in 1947 [2], first produced artificially in lab in 1948 for charged pions [3–4] and in 1950 for the first detection of the neutral pion [5–6]. Pions are unstable and quickly decay into other particles. The primary decay mode of the charged pion mesons is to emit a muon and a muon-type neutrino or antineutrino, while for the neutral pion the primary decay mode is to emit two gamma-ray photons [7].

Table 1 lists the fundamental physical properties of pions including their quark compositions, masses, lifetimes, isospins, electric charges, and major, minor, and rare modes of decays [8–9]. It is seen that the charged pions are slightly more massive than the neutral pion and the latter has a lifetime much shorter than the charged ones. They are bosonic with isospins of 1, -1 , and 0 and the lightest mesons or hadrons with masses about 139.57 MeV for $\pi^\pm$ and 134.98 MeV for π^0 , so that participate in the strong interaction as exchangers or nuclear force carriers. Gluons are the carriers of the fundamental strong force between color charges of quarks, while pions are the carriers of the nuclear force between nucleons at low energies.

Table 1: Pion mesons and their physical properties: quark composition, mass, lifetime, isospin, electric charge, and decay mode.

Pion Meson	π^+	π^-	π^0
Quark	$u\bar{d}$	$\bar{u}d$	$u\bar{u}, d\bar{d}$, or mix
Mass (MeV)	139.57	139.57	134.98
Lifetime	26 ns	26 ns	85 attosecond
Isospin	+1	-1	0
Charge	+e	-e	0
Major Decay	$\mu^+ \nu_\mu$	$\mu^- \bar{\nu}_\mu$	2γ
Minor Decay	$e^+ \nu_e$	$e^- \bar{\nu}_e$	$\gamma e^- e^+$
Rare Decay	$\pi^0 e^+ \nu_e$	$\pi^0 e^- \bar{\nu}_e$	$e^- e^+, 2e^- 2e^+$

The standard model of particle physics (SM) has shown, from the Feynman diagrams, what particles that pions can decay via different modes, but it does not explain why and how pions decay and have those various modes. The objective of this paper is to explore why and how these various decay modes of pions occur according to the newly developed two-flavor multi-excitation quark model, which exhibits us a new quantum world of quarks. We will provide the fine structures of Feynman diagrams for each decay mode and show how the corresponding particles are emitted or formed from the decays via quark-antiquark pair emissions and annihilations. Pions have different quark states and hence decay via different modes. Excited quarks get relaxation via quark-antiquark emissions and leptons are formed via quark-antiquark anni-

hilitations. The fine structures of Feynman diagrams show the fine processes of quark decays and particle formations.

2 Pion decay modes and Feynman diagrams

The charged pions decay mostly into muon leptons with a branching factor given by 0.999877 ($\pi^+ \rightarrow \mu^+ + \nu_\mu$, $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$), traceably into electron leptons with a branching factor given by 0.000123 ($\pi^+ \rightarrow e^+ + \nu_e$, $\pi^- \rightarrow e^- + \bar{\nu}_e$), and rarely into a neutral pion with electron leptons with a branching factor of about 10^{-8} ($\pi^+ \rightarrow \pi^0 + e^+ + \nu_e$, $\pi^- \rightarrow \pi^0 + e^- + \bar{\nu}_e$). The neutral pion usually decays into two gamma rays with a branching factor given by 0.98823 ($\pi^0 \rightarrow 2\gamma$). The second largest decay mode for neutral pions is the Dalitz decay with a branching factor given by 0.01174 ($\pi^0 \rightarrow \gamma + e^- + e^+$). A neutral pion can also rarely decay into one or two electron-positron pairs ($\pi^0 \rightarrow e^- + e^+$, $\pi^0 \rightarrow 2e^- + 2e^+$) with branching factors given by 6×10^{-8} and 3×10^{-5} , respectively [7].

As a meson, each pion consists of a quark and an antiquark [10]. The positively charged pion consists of one up quark and one antidown quark, i.e. $\pi^+(u\bar{d})$. The negatively charged pion consists of one down quark and one antiup quark, i.e. $\pi^-(d\bar{u})$, which is the antiparticle of the positively charged pion. The neutral pion can be a combination of an up quark and an antiup antiquark, a down quark and an antidown antiquark, or a mix combination of an up-antiup quark pair and a down-antidown quark pair, i.e. $\pi^0(u\bar{u}, d\bar{d}, \text{ or } (u\bar{u} \pm d\bar{d})/\sqrt{2})$. Figure 1 sketches the Feynman diagrams of both the positively and negatively charged pions to decay to the major mode (muon leptons) and minor mode (electron leptons), while Figure 2 shows the Feynman diagrams for them to decay into the rare mode (electron leptons with a neutral pion) [11, 7]. Figure 3 sketches the Feynman diagrams of the neutral pion to decay to the major mode (two gamma rays) and minor mode (one gamma ray with a pair of electron and positron), while Figure 4 shows the neutral pion to decay into the rare mode (one pair or two pairs of electron and positron). The SM explains these decays to be caused by the weak interactions between leptons and quarks. The weak interaction is carried by the weak bosons $W^\pm$ and Z^0 . Leptons are participants of the weak interaction, while the neutral pion decays into two gamma rays is driven by the electromagnetic interaction.

3 The new quantum world of quarks

Based on his newly well-developed four-element theory of nature [12–14], which later has been simplified into three-element theory of nature by defining radiation an equivalent mass [15], Zhang has recently developed a new model of quarks with only up and down two flavors but multiple excitation states, called to the two-flavor multi-excitation model of quarks [16–18]. This new quark model brings us a new quantum world of quarks for not only deeper understanding

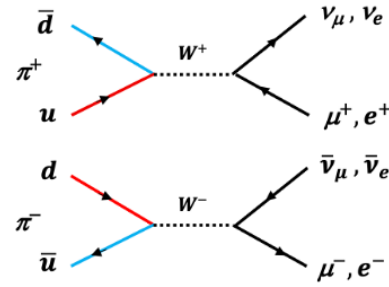


Fig. 1: (a) Top panel shows the Feynman diagrams of positively charged pion $\pi^+(u\bar{d})$ to decay to the major mode (μ^+, ν_μ) or the minor mode (e^+, ν_e). (b) Bottom panel shows the Feynman diagrams of negatively charged pion $\pi^-(\bar{u}d)$ to decay to the major mode ($\mu^-, \bar{\nu}_\mu$) or the minor mode ($e^-, \bar{\nu}_e$).

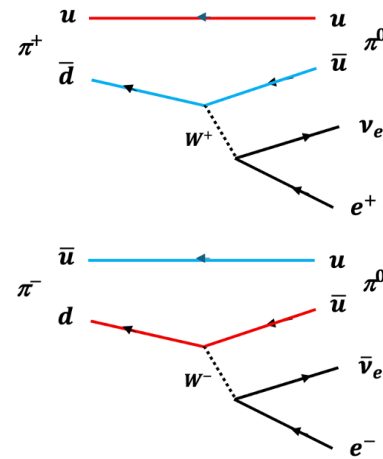


Fig. 2: (a) Top panel shows the Feynman diagrams of positively charged pion $\pi^+(u\bar{d})$ to decay to the rare mode (π^0, e^+, ν_e). (b) Bottom panel shows the Feynman diagrams of negatively charged pion $\pi^-(\bar{u}d)$ to decay to the rare mode ($\pi^0, e^-, \bar{\nu}_e$).

of how quarks get excited and decay, how particles are formed and generated, and how they interact and transmute but also for creative insights into mysteries of antimatter missing and dark matter's origin in the universe [19–22]. This new quantum world of quarks exhibits a new universe to be composed of four or three fundamental elements, which include radiation, mass, electric charge, and color charge or mass, electric charge, and color charge when we define radiation an equivalent mass, built up by two building blocks or two flavors of quarks (up and down only), which can have infinitely excited states, and governed by four real and two imaginary fundamental interactions.

From the new four-element theory of nature or the simplified three-element theory of nature, the fundamental weak interaction is an interaction between electric and color charges, so that can occur inside a single quark (Figure 5) and cause the quark decay or get excited. Quarks only need two flavors (up and down quarks) but they have multiple excited states above their ground states. The traditional heavy fla-

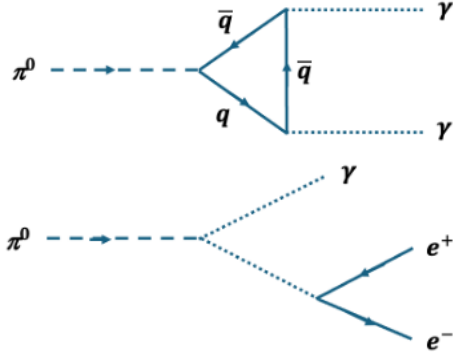


Fig. 3: (a) Top panel shows the Feynman diagram of a neutral pion to decay to the major mode $\pi^0 \rightarrow 2\gamma$. (b) Bottom panel shows the Feynman diagram of a neutral pion to decay to the minor mode $\pi^0 \rightarrow \gamma + e^- + e^+$.

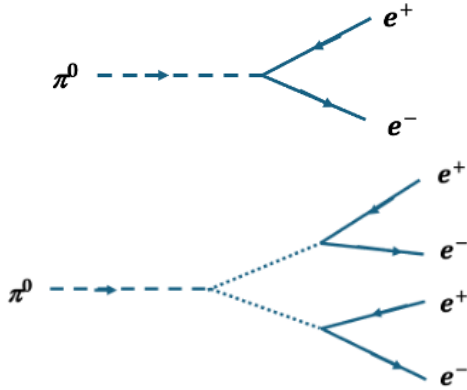


Fig. 4: (a) Top panel shows the Feynman diagram of a neutral pion to decay into the rare mode: one electron-positron pair ($\pi^0 \rightarrow e^- + e^+$). (b) Bottom panel shows the Feynman diagram of a neutral pion to decay to the rare mode: two electron-positron pairs ($\pi^0 \rightarrow 2e^- + 2e^+$).

vor quarks in the standard model of particle physics (i.e. the charm, strange, top, and bottom quarks) are treated as the second and third excited states of the up and down quarks (Figure 6). All particles including leptons, bosons, and hadrons are formed from combinations of two or more quarks and antiquarks in various states. The ordinary matter of the present universe is made up of these two fundamental building blocks: up and down quarks. Quarks get excited and decay via absorbing or emitting a quark-antiquark pair (Figure 7). Leptons are products rather than participants of the weak interactions.

In the two-flavor multi-excitation model of quarks [16], combinations of two quarks, in which one is antiquark, form in maximum eight different types of particles via different level annihilations among their masses, electric charges, and color charges of the quark and antiquark. The eight types of particles are massive and massless mesons and gluons, electrically neutral and charged leptons, Weyl fermions, and photons (Figure 8). A quark combines with an antiquark to

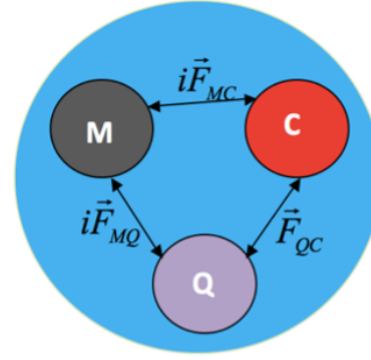


Fig. 5: A sketch for the fundamental elements and interactions of quark. A quark is a composite of mass M , electric charge Q , and color charge C . Interaction among the fundamental elements include one real interaction (called the weak force) between electric charge and color charge and two imaginary forces between mass and electric charge and between mass and color charge.

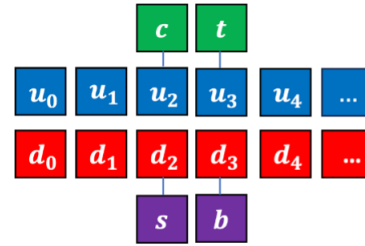


Fig. 6: This sketch shows the quark flavors and states in the two-flavor multi-excitation model of quarks. Quarks have only two flavors, denoted also up and down quarks like the standard model of particle physics, but have multiple excitation states, from the ground state (u_0, d_0), first excited state (u_1, d_1), second excited state (u_2, d_2), third excited state (u_3, d_3), etc. and in principle to the infinitely excited state (u_∞, d_∞). The traditional heavy flavor quarks: charm, strange, top, and bottom are treated as the second and third excitation states of the up and down quarks, i.e., ($c = u_2, s = d_2, t = u_3, b = d_3$).

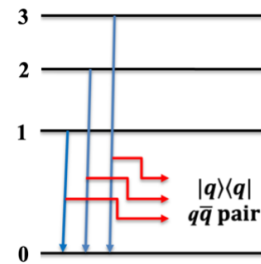


Fig. 7: This sketch shows that a quark decays via emitting a pair of quark and antiquark. An excited quark relaxes or decays into non-excited quark by emitting a quark-antiquark pair, while a quark gets excited when it absorbs a quark-antiquark pair.

form a meson if no annihilation occurs, a charged lepton if color charges annihilate, a neutrino if both electric and color charges annihilate, a photon if all masses, electric and color charges annihilate, a Weyl fermion if both masses and color

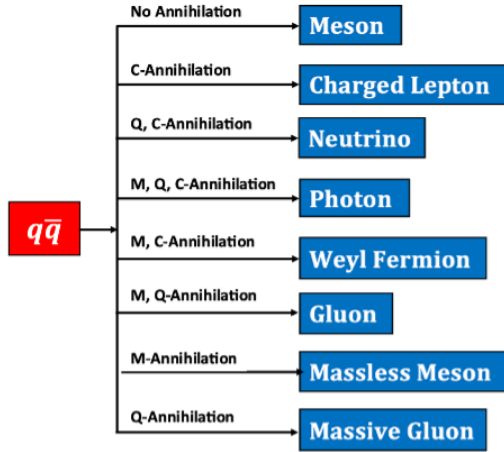


Fig. 8: Combinations of a quark and an antiquark can form in maximum eight types of particles via different level annihilations between their masses, electric charges, and color charges.

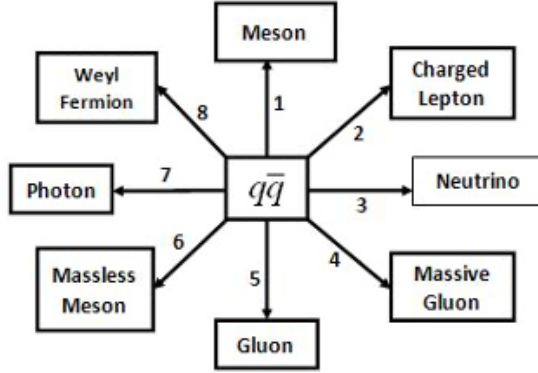


Fig. 9: This diagram orders the eight different types of quark-antiquark combinations and corresponding types of particles formed from quark-antiquark combinations [16].

charges annihilate, a gluon if both masses and electric charges annihilate, a massless meson if masses annihilate, and a massive gluon (or called coloron) if electric charges annihilate (Figure 9).

The charge annihilations of a quark and an antiquark up to the first excitations states form the first four generations of twelve leptons (Table 2). These annihilations that form twelve leptons are: (1) an annihilation of both electric and color charges between a ground state up quark and a ground state antiup antiquark forms a stable electron-type neutrino or antineutrino $\langle u_0|u_0 \rangle_3 \rightarrow \nu_e$ or $\bar{\nu}_e$; (2) an annihilation of both electric and color charges between a ground state down quark and a ground state antidown antiquark forms a stable muon-type neutrino or antineutrino $\langle d_0|d_0 \rangle_3 \rightarrow \nu_\mu$ or $\bar{\nu}_\mu$; (3) an annihilation of both electric and color charges between a first excited state up quark and a first excited state antiup antiquark forms a tau-type neutrino or antineutrino $\langle u_1|u_1 \rangle_3 \rightarrow \nu_\tau$ or $\bar{\nu}_\tau$; (4) an annihilation of both electric and color charges

Table 2: Twelve leptons (four generations) that are formed from color and/or electric charge annihilations between the ground and first excited up and down quarks and antiquarks.

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

between a first excited state down quark and a first excited state antidown antiquark forms a lambda-type neutrino or antineutrino $\langle d_1|d_1 \rangle_3 \rightarrow \nu_\lambda$ or $\bar{\nu}_\lambda$; (5) an annihilation of color charges between a ground state down quark and a ground state antiup antiquark forms a stable electron $\langle u_0|d_0 \rangle_2 \rightarrow e^-$; (6) an annihilation of color charges between a ground state up quark and a ground state antidown antiquark forms a stable positron $\langle d_0|u_0 \rangle_2 \rightarrow e^+$; (7) an annihilation of color charges between a ground state down quark and a first excited state antiup antiquark forms an unstable negatively charged muon $\langle u_1|d_0 \rangle_2 \rightarrow \mu^-$; (8) an annihilation of color charges between a first excited state up quark and a ground state antidown antiquark forms an unstable positively charged muon $\langle d_0|u_1 \rangle_2 \rightarrow \mu^+$; (9) an annihilation of color charges between a first excited state down quark and a ground state antiup antiquark forms an unstable negatively charged tau lepton $\langle u_0|d_1 \rangle_2 \rightarrow \tau^-$; (10) an annihilation of color charges between a ground state up quark and a first excited state antidown antiquark forms an unstable positively charged tau lepton $\langle d_1|u_0 \rangle_2 \rightarrow \tau^+$; (11) an annihilation of color charges between an excited state down quark and an excited state antiup antiquark forms an unstable negatively charge lambda lepton $\langle u_1|d_1 \rangle_2 \rightarrow \lambda^-$; and (12) an annihilation of color charges between a first excited state up quark and a first state antidown antiquark forms an unstable positively charged lambda lepton $\langle d_1|u_1 \rangle_2 \rightarrow \lambda^+$.

There are another four quark-antiquark combinations that are question-marked in Table 2: $(u_0, \bar{u}_1)$, $(u_1, \bar{u}_0)$, $(d_0, \bar{d}_1)$, and $(d_1, \bar{d}_0)$. Each of these combinations 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 pion 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 $|u_1\rangle \rightarrow |u_0\rangle\langle u_0|u_0\rangle$, where the ground up quark and the ground antiup quark annihilate their charges to form an electron-type neutrino or antineutrino or annihilate

Table 3: Sixteen (fourteen independent) states of pion mesons that are formed from combinations between the ground and first excited up and down quarks and antiquarks without annihilations.

	$\bar{u}_0$	$\bar{d}_0$	$\bar{u}_1$	$\bar{d}_1$
u_0	$\pi_{00}^{0,u}$	π_{00}^+	$\pi_{01}^{0,u}$	π_{01}^+
d_0	π_{00}^-	$\pi_{00}^{0,d}$	π_{01}^-	$\pi_{01}^{0,d}$
u_1	$\pi_{10}^{0,u}$	π_{10}^+	$\pi_{11}^{0,u}$	π_{11}^+
d_1	π_{10}^-	$\pi_{10}^{0,d}$	π_{11}^-	$\pi_{11}^{0,d}$

their charges and also 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. In addition, the charge annihilations between ground states of up and down quarks form stable particles, including electron, positron, electron-type neutrino, and muon-type neutrino.

4 Multiple states of pions and various modes of decays

Combinations of a quark and an antiquark up to the first excited states without annihilations form 16 possible states of pion mesons (Table 3). According to their electric charges, we can classify them into three categories: neutral pion π^0 , positively charged pion π^+ , and negatively charged pion π^- . The neutral pion has eight different states and two different flavors $\pi^0 = \{\pi_{00}^{0,u}, \pi_{01}^{0,u}, \pi_{10}^{0,u}, \pi_{11}^{0,u}, \pi_{00}^{0,d}, \pi_{01}^{0,d}, \pi_{10}^{0,d}, \pi_{11}^{0,d}\}$, in which six states are independent as a neutral pion's antiparticle is itself (i.e.: $\pi_{01}^{0,u} = \pi_{10}^{0,u}$ and $\pi_{01}^{0,d} = \pi_{10}^{0,d}$). The positively charged pion has four different states $\pi^+ = \{\pi_{00}^+, \pi_{01}^+, \pi_{10}^+, \pi_{11}^+\}$. The negatively charged pion has also four different states $\pi^- = \{\pi_{00}^-, \pi_{01}^-, \pi_{10}^-, \pi_{11}^-\}$.

Mesons are all unstable and quickly decay. Those pion states formed by combinations of the ground up and down quark-antiquark states are immediately and directly annihilated into those stable leptons and gamma rays: (1) $\pi_{00}^{0,u} \equiv (u_0, \bar{u}_0) \rightarrow \nu_e, \bar{\nu}_e$, or γ , (2) $\pi_{00}^{0,d} \equiv (d_0, \bar{d}_0) \rightarrow \nu_\mu, \bar{\nu}_\mu$, or γ , (3) $\pi_{00}^+ \equiv (u_0, \bar{d}_0) \rightarrow e^+$, and (4) $\pi_{00}^- \equiv (d_0, \bar{u}_0) \rightarrow e^-$. These four ground-state pions are directly annihilated into stable state leptonic and bosonic particles including electron, positron, electron-type neutrino and antineutrino, and muon-type neutrino and antineutrino, including gamma rays. Other excited pion states formed with one or two excited up or down quarks or antiquarks are quickly decayed into other particles via various (major, minor, and rare) decay modes according to the decays or transmutations of their excited quarks and antiquarks: (5) $\pi_{10}^{0,u} \equiv (u_1, \bar{u}_0) \rightarrow 2\gamma$ or $e^- + e^+$ or $\nu_e + \bar{\nu}_e$, (6) $\pi_{11}^{0,u} \equiv (u_1, \bar{u}_1) \rightarrow \gamma + e^- + e^+$, (7) $\pi_{10}^{0,d} \equiv (d_1, \bar{d}_0) \rightarrow 2\gamma$ or $e^- + e^+$ or $\nu_\mu + \bar{\nu}_\mu$, (8) $\pi_{11}^{0,d} \equiv (d_1, \bar{d}_1) \rightarrow \gamma + e^- + e^+$, (9) $\pi_{10}^+ \equiv (u_1, \bar{d}_0) \rightarrow e^+ + \nu_e$, (10) $\pi_{01}^+ \equiv (u_0, \bar{d}_1) \rightarrow e^+ + \nu_e$, (11) $\pi_{11}^+ \equiv (u_1, \bar{d}_1) \rightarrow \mu^+ + \nu_\mu$ or $\pi^0 + e^+ + \nu_e$, (12) $\pi_{01}^- \equiv (d_0, \bar{u}_1) \rightarrow e^- + \bar{\nu}_e$, (13) $\pi_{10}^- \equiv (d_1, \bar{u}_0) \rightarrow e^- + \bar{\nu}_e$, (14)

$\pi_{11}^- \equiv (d_1, \bar{u}_1) \rightarrow \mu^- + \bar{\nu}_\mu$ or $\pi^0 + e^- + \bar{\nu}_e$. It is seen that pions exist in different states and thus decay into different particles through different decay modes.

We should note here that the neutral pion has also long-type and short-type from the mix combinations of quarks and antiquarks $(u_i \bar{u}_j \pm d_i \bar{d}_j) / \sqrt{2}$, where $i, j = 0, 1$. The long-type or short-type neutral pion formed from the mix combinations, $(u_1 \bar{u}_0 \pm d_1 \bar{d}_0) / \sqrt{2}$ or $(u_0 \bar{u}_1 \pm d_0 \bar{d}_1) / \sqrt{2}$, can decay to the rare decay mode: two pairs of electrons and positrons.

5 The fine structures of Feynman diagrams for pion decays

In this section, we show the fine structures of those Feynman diagrams given in the above section for the fourteen different and independent states of pions to decay into various particles via various decay modes. We demonstrate them into ten Figures 10–19.

Figure 10 and Figure 11 show the decays of the four states of pions, which are formed from combinations between the ground-state up and down quarks and antiquarks. These four ground states of pions immediately annihilate their quark and antiquark into particles. The ground state of up-type neutral pion $\pi_{00}^{0,u}$, formed from the combination of the ground state up quark and antiup antiquark, annihilates its up and antiup's electric and color charges to form an electron-type neutrino or antineutrino (Figure 10's top panel). If their masses are also annihilated, the particle formed will be a gamma ray. The ground state of down-type neutral pion $\pi_{00}^{0,d}$, formed from the combination of the ground state down quark and antidown antiquark, annihilates its down and antidown's electric and color charges to form a muon-type neutrino or antineutrino (Figure 10's bottom panel). If their masses are also annihilated, the particle formed will be a gamma ray. The ground state of positively charged pion π_{00}^+ , formed from the combination of the ground state up quark and antidown antiquark, annihilates its up and antidown's color charges to form a positron (Figure 11's top panel). The ground state of negatively charged pion π_{00}^- , formed from the combination of the ground state down quark and antiup antiquark, annihilates its down and antiup's color charges to form an electron (Figure 11's bottom panel).

Figure 12 shows the fine structures of Feynman diagrams for the decays of the positively charged pions (π_{01}^+, π_{10}^+). The positively charged pion π_{01}^+ , formed from the combination of the ground state up quark and first-excited antidown antiquark, decays into a positron and an electron-type neutrino (Figure 12's top panel). The entire decay process involves three subprocesses: (1) the excited antidown quark transmutes its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (2) the ground state up quark of the positively charged pion and the ground state antiup antiquark of the emitted quark-antiquark pair annihilate their electric and color charges into an electron-type neutrino; (3) the ground antidown antiquark transmuted from the

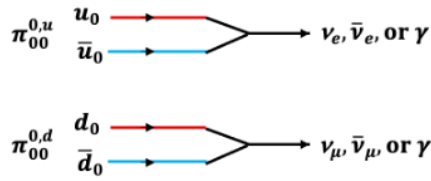


Fig. 10: The ground-state neutral pion mesons formed from combinations between the ground-state up and down quarks and antiquarks immediately annihilate both electric and color charges into stable neutral leptons, including electron-type and muon-type neutrinos or antineutrinos, or gamma rays.

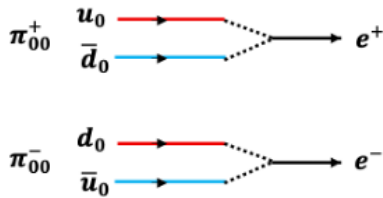


Fig. 11: Charged pion mesons formed from combinations between the ground-state up and down quarks and antiquarks immediately annihilate color charges into stable charged leptons, including electrons and positrons.

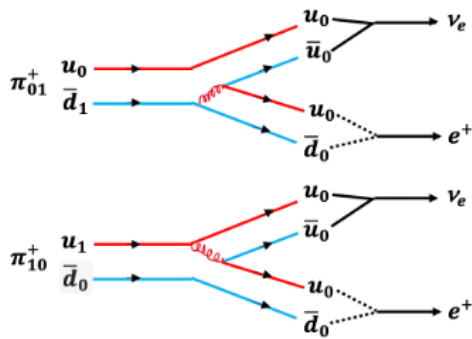


Fig. 12: The positively charge pion, if it is formed with one first-excited quark or antiquark and one ground state antiquark or quark, decays into a positron and an electron-type neutrino (minor mode).

positively charged pion and the ground state up quark of the emitted quark-antiquark pair annihilate their color charge into a positron. The positively charged pion π_{10}^+ , formed from the combination of the first excited state up quark and the ground state antidown antiquark, decays also into a positron and an electron-type neutrino (Figure 12's bottom panel). The entire decay process also involves three subprocesses: (1) the excited up quark transmutes its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (2) The ground state antidown antiquark of the positively charged pion and the ground state up quark of the emitted quark-antiquark pair annihilate their color charges into a positron; (3) The ground state up quark transmuted from the positively charged pion and the ground state antiup antiquark of the emitted quark-antiquark pair annihilate their electric and color charges into an electron-type neutrino.

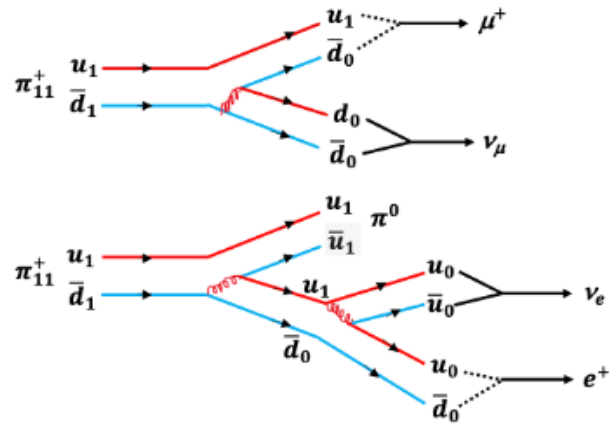


Fig. 13: The positively charged pion, if it is formed by the first excited up quark and antidown antiquark, decays into a positively charged muon and a muon-type neutrino (major mode) or into a neutral pion, a positron, and an electron-type neutrino (rare mode).

Figure 13 shows the fine structures of Feynman diagrams for the decays of the positively charged pions (π_{11}^+). The positively charged pion π_{11}^+ , formed from the combination of the first excited up quark and antidown antiquark, decays into a positively charged muon and a muon-type neutrino (Figure 13's top panel). The entire decay process involves three subprocesses: (1) the excited antidown quark transmutes its state to the ground state via emitting a ground state down and antidown quark-antiquark pair; (2) The first excited state up quark of the positively charged pion and the ground state antidown antiquark of the emitted quark-antiquark pair annihilate their color charges into a positively charged muon; (3) The ground antidown antiquark transmuted from the positively charged pion and the ground state down quark of the emitted quark-antiquark pair annihilate their electric and color charges into a muon-type neutrino. The positively charged pion π_{11}^+ can also decay but rarely into a neutral pion, a positron, and an electron-type neutrino (Figure 13's bottom panel). The entire decay process involves five subprocesses: (1) the excited antidown quark transmutes its state to the ground state via emitting a first excited state up and antiup quark-antiquark pair; (2) The first excited state up quark of the positively charged pion and the first excited state antiup antiquark of the emitted quark-antiquark pair combine without annihilation into a neutral pion; (3) The first excited state up quark of the emitted quark-antiquark pair transmutes its state to a ground state up quark with emission of a ground state up and antiup quark-antiquark pair; (4) the ground state up quark transmuted from the first emitted quark-antiquark pair and the ground state antiup antiquark of the second emitted quark-antiquark pair annihilate their electric and color charge to form an electron-type neutrino; (5) the ground state antidown antiquark transmuted from the positively charged pion and the ground state up quark of the second emitted quark-antiquark pair annihilate their color charges into a positron.

Figure 14 shows the fine structures of Feynman diagrams for the decays of the negatively charged pions (π_{01}^-, π_{10}^-). The negatively charged pion π_{01}^- , formed from the combination of the ground state down quark and first-excited antiup antiquark, decays into an electron and an electron-type antineutrino (Figure 14's top panel). The entire decay process involves three subprocesses: (1) the excited antiup quark transmutes its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (2) the ground state down quark of the negatively charged pion and the ground state antiup antiquark of the emitted quark-antiquark pair annihilate their color charges into an electron; (3) the ground antiup antiquark transmuted from the negatively charged pion and the ground state up quark of the emitted quark-antiquark pair annihilate their electric and color charges into an electron-type antineutrino. The negatively charged pion π_{10}^- , formed from the combination of the first excited state down quark and the ground state antiup antiquark, decays also into an electron and an electron-type antineutrino (Figure 14's bottom panel). The entire decay process also involves three subprocesses: (1) the excited down quark transmutes its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (2) the ground state antiup antiquark of the negatively charged pion and the ground state up quark of the emitted quark-antiquark pair annihilate their electric and color charges into an electron-type antineutrino; (3) the ground state down quark transmuted from the negatively charged pion and the ground state antiup antiquark of the emitted quark-antiquark pair annihilate their color charges into an electron.

Figure 15 shows the fine structures of Feynman diagrams for the decays of the negatively charged pions (π_{11}^-). The negatively charged pion π_{11}^- , formed from the combination of the first excited down quark and antiup antiquark, decays into a negatively charged muon and a muon-type antineutrino (Figure 15's top panel). The entire decay process involves three subprocesses: (1) the excited down quark transmutes its state to the ground state via emitting a ground state down and antidown quark-antiquark pair; (2) the first excited state antiup antiquark of the negatively charged pion and the ground state down quark of the emitted quark-antiquark pair annihilate their color charges into a negatively charged muon; (3) the ground down quark transmuted from the negatively charged pion and the ground state antidown antiquark of the emitted quark-antiquark pair annihilate their electric and color charges into a muon-type antineutrino. The negatively charged pion π_{11}^- can also decay but rarely into a neutral pion, an electron, and an electron-type antineutrino (Figure 15's bottom panel). The entire decay process involves five subprocesses: (1) the excited down quark transmutes its state to the ground state via emitting a first excited state up and antiup quark-antiquark pair; (2) the first excited state antiup antiquark of the negatively charged pion and the first excited state up quark of the emitted quark-antiquark pair combine without

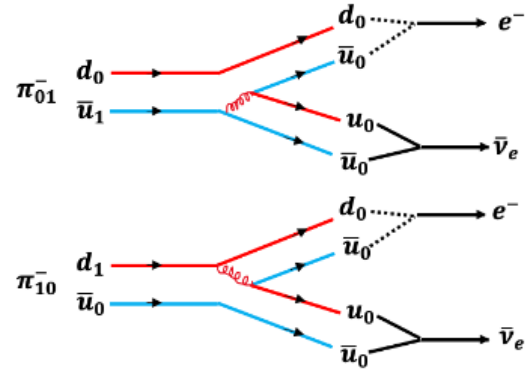


Fig. 14: The negatively charged pion, if it is formed with one first-excited quark or antiquark and one ground antiquark or quark, decays into an electron and an electron-type antineutrino (minor mode).

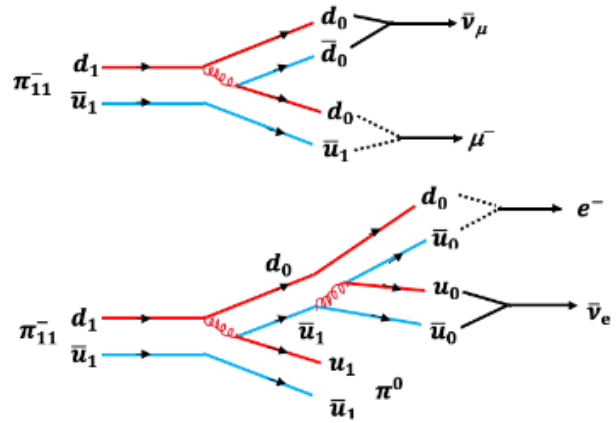


Fig. 15: The negatively charged pion, if it is formed by the first excited down quark and antiup antiquark, decays into a negatively charged muon and a muon-type antineutrino (major mode) or into a neutral pion, an electron, and an electron-type antineutrino (rare mode).

annihilation into a neutral pion; (3) the first excited state antiup antiquark of the emitted quark-antiquark pair transmutes its state to a ground state antiup with emission of a ground state up and antiup quark-antiquark pair; (4) the ground state antiup antiquark transmuted from the first emitted quark-antiquark pair and the ground state up quark of the second emitted quark-antiquark pair annihilate their electric and color charge to form an electron-type antineutrino; (5) the ground state down quark transmuted from the negatively charged pion and the ground state antiup antiquark of the second emitted quark-antiquark pair annihilate their color charges into an electron.

Figure 16 and Figure 17 show the decays of neutral pions that are formed from combinations of a first excited state quark and a ground state antiquark. The up-type neutral pion $\pi_{10}^{0,u}$, formed from the combination of a first excited state up quark and a ground state antiup antiquark (Figure 16's top panel), decays into a pair of gamma rays or a pair of electron-

type neutrino and antineutrino. The entire decay process involves three subprocesses: (1) the excited up quark transmutes its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (2) the ground state up quark transmuted from the neutral pion and the ground state antiup antiquark of the emitted quark-antiquark pair annihilate their masses, electric charges, and color charges into a gamma ray or an electron-type neutrino or antineutrino if their masses are not annihilated; (3) the ground antiup antiquark of the neutral pion and the ground state up quark of the emitted quark-antiquark pair annihilate their masses, electric charges, and color charges into a gamma ray or an electron-type neutrino or antineutrino if their masses are not annihilated. The down-type neutral pion $\pi_{10}^{0,d}$, formed from the combination of a first excited state down quark and a ground state antidown antiquark, decays also into a pair of gamma rays or a pair of muon-type neutrino and antineutrino (Figure 16's bottom panel). The entire decay process also involves three subprocesses: (1) the excited down quark transmutes its state to the ground state via emitting a ground state down and antidown quark-antiquark pair; (2) The ground state down quark transmuted from the neutral pion and the ground state antidown quark of the emitted quark-antiquark pair annihilate their masses, electric charges, and color charges into a gamma ray or a muon-type of neutrino or antineutrino if their masses are not annihilated; (3) The ground antidown quark of the neutral pion and the ground state down quark of the emitted quark-antiquark pair annihilate their masses, electric charges, and color charges into a gamma rays or a muon-type neutrino or antineutrino if their masses are not annihilated.

If the excited quark transmutes its state to the ground state with emission of a different flavor quark-antiquark pair, the neutral pion decays into a pair of electron and positron (Figure 17). The up-type neutral pion $\pi_{10}^{0,u}$, formed from combination of a first excited state up quark and a ground state antiup antiquark (Figure 17's top panel), decays into a pair of electron and positron. The entire decay process involves three subprocesses: (1) the excited up quark transmutes its state to the ground state via emitting a ground state down and antidown quark-antiquark pair; (2) the ground state up quark transmuted from the neutral pion and the ground state antidown antiquark of the emitted quark-antiquark pair annihilate their color charges into a positron; (3) the ground antiup antiquark of the neutral pion and the ground state down quark of the emitted quark-antiquark pair annihilate their color charges into an electron. The down-type neutral pion $\pi_{10}^{0,d}$, formed from the combination of the first excited state down quark and the ground state antidown antiquark, decays also into a pair of electron and positron (Figure 17's bottom panel). The entire decay process also involves three subprocesses: (1) the excited down quark transmutes its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (2) The ground state down quark transmuted from the neutral

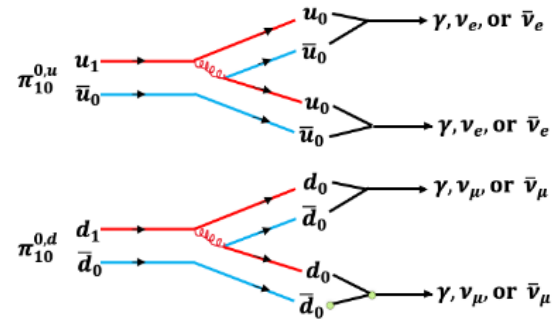


Fig. 16: Fine structure of Feynman diagrams for the decays of the up-type and down-type neutral pions that are formed from combinations of a first excited quark and a ground state antiquark. When their excited quarks emit a ground state and same flavor quark-antiquark pair, they decay into a pair of gamma rays (major mode), including also possibly a pair of electron-type or muon-type neutrino and antineutrino.

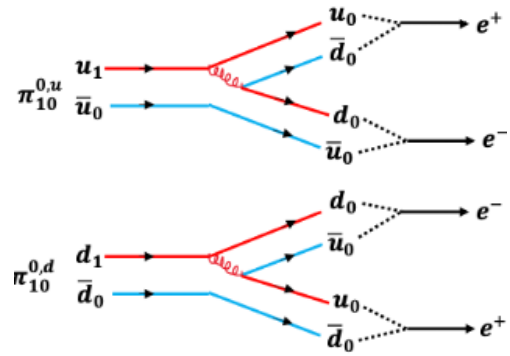


Fig. 17: Fine structure of Feynman diagrams for the decays of the up-type and down-type neutral pions that are formed from combinations of a first excited quark and a ground state antiquark. When their excited quarks emit a ground state and different flavor quark-antiquark pair, they decay into a pair of electron and positron (rare mode).

pion and the ground state antiup quark of the emitted quark-antiquark pair annihilate their color charges into an electron; (3) The ground state antidown quark of the neutral pion and the ground state up quark of the emitted quark-antiquark pair annihilate their color charges into a positron.

Figure 18 and Figure 19 show the decays of neutral pions that are formed from combinations of a first excited state quark and a first excited state antiquark. The up-type neutral pion $\pi_{11}^{0,u}$, formed from the combination of a first excited state up quark and a first excited state antiup antiquark (Figure 18's top panel), decays into a gamma ray and a pair of electron and positron. The entire decay process involves five subprocesses: (1) the excited up quark transmutes its state to the ground state via emitting a ground state down and antidown quark-antiquark pair; (2) the ground state up quark transmuted from the neutral pion and the ground state antidown antiquark of the emitted quark-antiquark pair annihilate their color charges into a positron; (3) the first excited antiup

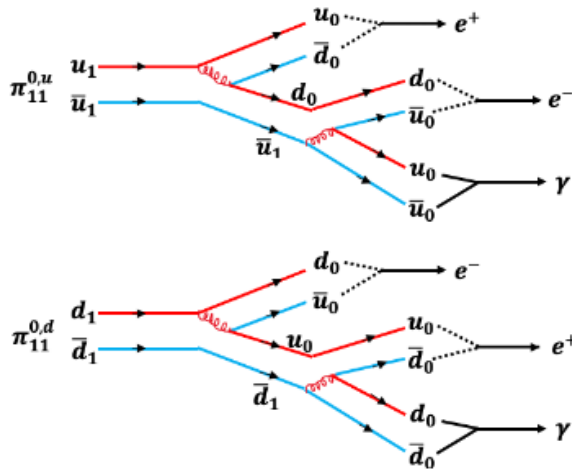


Fig. 18: Fine structure of Feynman diagrams for the decays of the up-type and down-type neutral pions that are formed from combinations of a first excited quark and a first excited state antiquark. When their excited quarks emit a ground state and different flavor quark-antiquark pair, they decay into a pair of electron and positron and a gamma ray (minor mode).

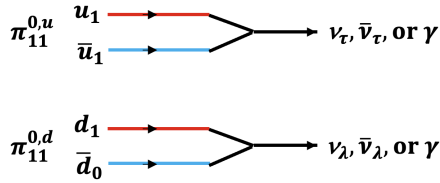


Fig. 19: The up-type and down-type neutral pions that are formed from combinations of a first excited quark and a first excited state antiquark may also directly annihilate both electric and color charges of their quarks and antiquarks into a tau or lambda neutrino or antineutrino or a gamma ray.

antiquark transmuted from its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (4) the ground state down quark of the first emitted quark-antiquark pair and the ground state antiup antiquark annihilate their color charges into an electron; (5) the ground state antiup quark transmuted from the neutral pion and the ground state up quark of the second emitted quark-antiquark pair annihilate their masses, electric charges, and color charges into a gamma ray. The down-type neutral pion $\pi_{11}^{0,d}$, formed from the combination of the first excited state down quark and the first state antidown antiquark, decays also into a gamma ray and a pair of electron and positron (Figure 18's bottom panel). The entire decay process also involves five subprocesses: (1) the excited down quark transmutes its state to the ground state via emitting a ground state up and antiup quark-antiquark pair; (2) The ground state down quark transmuted from the neutral pion and the ground state antiup quark of the emitted quark-antiquark pair annihilate their color charges into an electron; (3) the first excited antidown antiquark transmuted

its state to the ground state via emitting a ground state down and antidown quark-antiquark pair; (4) the ground state up quark of the first emitted quark-antiquark pair and the ground state antidown antiquark annihilate their color charges into a positron; (5) the ground state antidown quark transmuted from the neutral pion and the ground state down quark of the second emitted quark-antiquark pair annihilate their masses, electric charges, and color charges into a gamma ray.

In addition, the up-type neutral pion $\pi_{11}^{0,u}$, formed from the combination of a first excited state up quark and a first excited state antiup antiquark (Figure 19's top panel), can directly annihilate their electric and color charges into a tau-type neutrino or antineutrino or a gamma ray when their masses are also annihilated. The down-type neutral pion $\pi_{11}^{0,d}$, formed from the combination of a first excited state down quark and a first excited state antidown antiquark (Figure 19's bottom panel), can directly annihilate their electric and color charges into a lambda-type neutrino or antineutrino or a gamma ray when their masses are also annihilated.

6 Conclusions

We have investigated the multiple states of pions and their various modes of decays based on Zhang's newly developed two-flavor multi-excitation model of quarks and new three or four-element theory of nature, which exhibits a new quantum world of quarks: the universe to be composed of three or four fundamental elements, made of two building blocks or two flavor multiply excitable quarks, and governed by six (four real and two imaginary) fundamental interactions. Pions, known as the light mesons, are composed of a quark and antiquark, whose color charges are not annihilated, and states are in either the ground or first excited states. Pions, in total, can have sixteen quark states, in which four ground state pions, composed of the ground state quark and antiquark, immediately annihilate into the observed stable particles including gamma ray, electron, positron, electron-type neutrino or antineutrino, and muon-type neutrino or antineutrino, and twelve (ten independent) excited state pions, composed of at least one first excited quark or antiquark, quickly decay into other particles via various decay modes as observed according to their quark and antiquark states through quark-antiquark pair emissions and annihilations. We have demonstrated the fine structures of Feynman diagrams for each decay modes of those excited state pions and shown how the corresponding particles formed from the decay via quark-antiquark emissions and annihilations.

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